AD-A034 416 CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAI--ETC F/G 21/4
TECHNICAL EVALUATION STUDY: SOLID WASTE AS A FUEL AT FT. BRAGG,--ETC(U)
DEC 76 S A HATHAWAY, J P WOODYARD

UNCLASSIFIED CERL-TR-E-95 NL

| OF |
AD
A034416

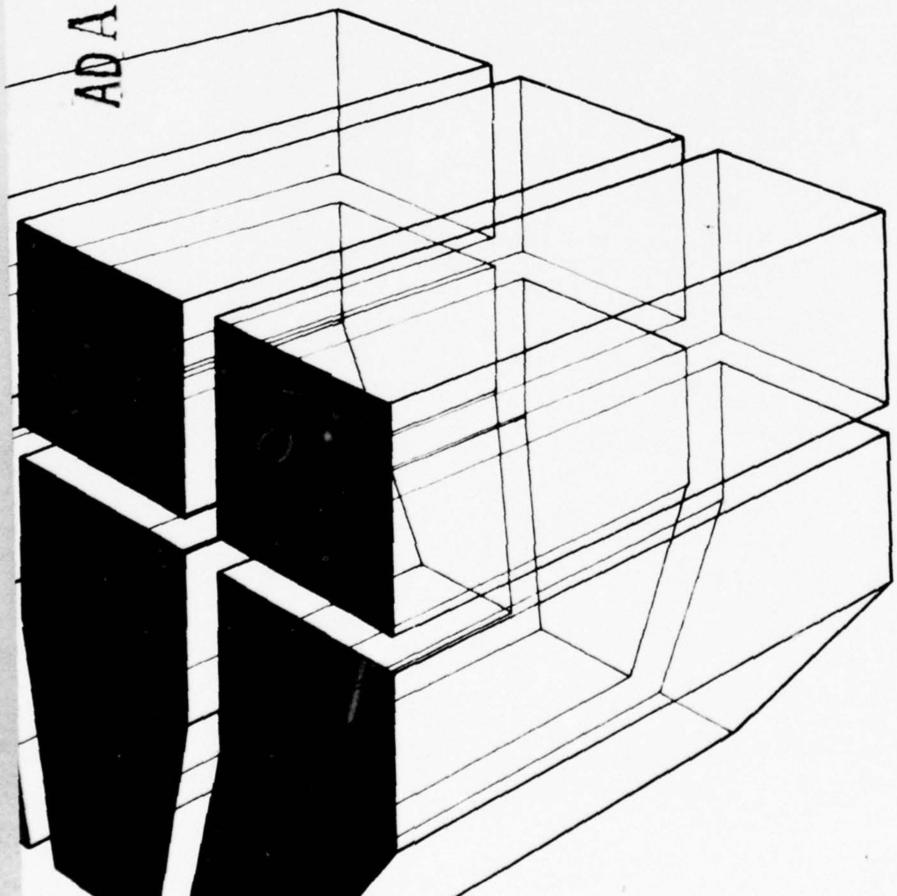
END
DATE
FILMED
2-77

construction
engineering
research
laboratory

12

TECHNICAL REPORT E-95
December 1976

TECHNICAL EVALUATION STUDY:
SOLID WASTE AS A FUEL AT FT. BRAGG, NC



by
S. A. Hathaway
J. P. Woodyard

CERL

Approved for public release; distribution unlimited.

USER EVALUATION OF REPORT

REFERENCE: Technical Report E-95, *Technical Evaluation Study: Solid Waste as a Fuel at Ft Bragg, NC*

Please take a few minutes to answer the questions below, tear out this sheet, and return it to CERL. As a user of this report, your customer comments will provide CERL with information essential for improving future reports.

1. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which report will be used.)

____

____

____

2. How, specifically, is the report being used? (Information source, design data or procedure, management procedure, source of ideas, etc.) ____

____

____

3. What is your evaluation of this report in the following areas?

   a. Presentation: ____

   b. Completeness: ____

   c. Easy to Understand: ___________________________________

   d. Easy to Implement: ____________________________________

   e. Adequate Reference Material: __________________________

   f. Relates to Area of Interest: __________________________

   g. Did the report meet your expectations? ________________

   h. Does the report raise unanswered questions? ___________

i. General Comments (Indicate what you think should be changed to make this report and future reports of this type more responsive to your needs, more usable, improve readability, etc.) __________

____

____

____

____

4. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

Name: ______________________________

Telephone Number: ______________________________

Organization Address: ______________________________

____

____

5. Please mail the completed form to:

Department of the Army
CONSTRUCTION ENGINEERING RESEARCH LABORATORY
ATTN: CERL-SOI
P.O. Box 4005
Champaign, IL 61820

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CERL-TR-E-95	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) TECHNICAL EVALUATION STUDY: SOLID WASTE AS A FUEL AT FT. BRAGG, N.C.		5. TYPE OF REPORT & PERIOD COVERED FINAL rept.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) S. A. Hathaway J. P. Woodyard		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS CONSTRUCTION ENGINEERING RESEARCH LABORATORY P.O. Box 4005 Champaign, IL 61820		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS IAO F&A 88-75
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE December 1976
		13. NUMBER OF PAGES 52 (12) 56p.
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Copies are obtainable from National Technical Information Service
Springfield, VA 22151

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

refuse-derived fuel
energy-recovery plant
incineration

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study investigated the technical and economic feasibility of using refuse as an energy resource at Ft. Bragg, NC. The technically proven system found to be most cost-effective uses mixed solid waste generated at both military (Ft. Bragg, Pope AFB) and civilian (City of Fayetteville) sources in the region. Refuse is delivered to an energy-recovery plant near the 82nd Airborne Division Heating Plant at Ft. Bragg, where it is processed into a refuse-derived fuel (RDF) by shredding and magnetic removal of ferrous materials. RDF is temporarily stored in a hopper until fed by screw

405 279

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

OVER

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Block 20 continued.

conveyor to the incinerator feed hopper, from which it is ram-fed into the furnace. The stoking mechanism is a three-flight double reciprocating grate. Saturated steam at 160 psig is produced in the boiler section after the furnace and fed to the main header of the nearby steam plant for distribution. Nearly 65,000 tons of refuse is processed annually. Steam production averages 54,000 lb/hour. An investment of $6.8 million is required (FY81 dollars). Approximately 3.1 million gal of fuel oil can be conserved annually. The savings/investment ratio is 3.74/1.0 with less than 3 years to payback. The system requires that the City of Fayetteville regularly deliver its solid waste to Ft. Bragg devoid of bulky incombustibles and particularly hazardous and obnoxious materials.

Review of alternative systems reveals that if the civilian sector chooses not to participate in the plan, energy recovery from the military refuse alone is still economically attractive. The military system consists of major equipment described above but reduced somewhat in size, and requires an investment of $5.3 million (FY81 dollars). Approximately 2.0 million gal of fuel oil can be conserved annually.

FOREWORD

This study was performed by the U.S. Army Construction Engineering Research Laboratory (CERL) for the Directorate of Facilities Engineering (DFAE), Ft. Bragg, NC, under Intra-Army Order F&A 88-75. MAJ J. MacMullen and Mr. C. Beard, DFAE, Ft. Bragg, were the Project Engineers. Mr. S. A. Hathaway of CERL served as the Principal Investigator. Assistance provided by MAJ F. Trainor, DFAE, Ft. Bragg, and Dr. G. Shih of the Energy Branch at CERL is acknowledged. Administrative support provided by Dr. D. J. Leverenz, Chief, Energy Branch, Mr. R. G. Donaghy, Chief, Energy and Power Division, and COL M. D. Remus, Commander and Director of CERL during most of the project period, is acknowledged.

COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

TABLES

TABLES (contd)

FIGURES

TECHNICAL EVALUATION STUDY: SOLID WASTE AS A FUEL AT FT. BRAGG, NC

1 INTRODUCTION

Background

Ft. Bragg (Figure 1) serves as the site of the U.S. Army 82nd Airborne Division, the U.S. Army Special Forces, the Airborne Communications and Electronics Test Group of the U.S. Army Development and Readiness Command, the U.S. Army Combat Development Group, the U.S. Army Parachute Team, and the U.S. Continental Army Command Intelligence Center (CONTIC). Pope AFB is adjacent to Ft. Bragg, and its mission is to support the 82nd Airborne Division.

Daily activities at Ft. Bragg and Pope AFB result in generation of conventional and special wastes. Traditionally, these military wastes have been collected and hauled by civilian employees of the installations and deposited in a sanitary landfill at Ft. Bragg. Wastes generated in the civilian sector are collected and hauled by numerous public and private haulers and disposed of in a variety of civilian landfills. Anticipating the approaching end of the functional life of the Ft. Bragg landfill, the Ft. Bragg Facilities Engineer has been investigating alternative means of disposing of military waste. According to the Facilities Engineer, nearby civilian systems of collecting and disposing of wastes have been found to be of questionable environmental compatibility, efficiency, and economic viability; this has encouraged civilian officials to join Ft. Bragg in searching for improved means of waste disposal.

Incineration has been recognized as a viable alternative to landfilling. The advantages of waste incineration include reduction of residual bulk of many solid and liquid wastes, conversion of most organic materials into gases which are already part of the natural atmosphere, and use of readily available oxygen from air as the principal chemical agent.[1] Unlike pyrolysis and other emerging energy-recovery technologies, incineration has proven applicable to liquid, solid, and gaseous wastes; it can be carried

[1]*Combustion Fundamentals for Waste Incineration* (American Society of Mechanical Engineers Research Committee on Industrial and Municipal Wastes, 1975), p IX.

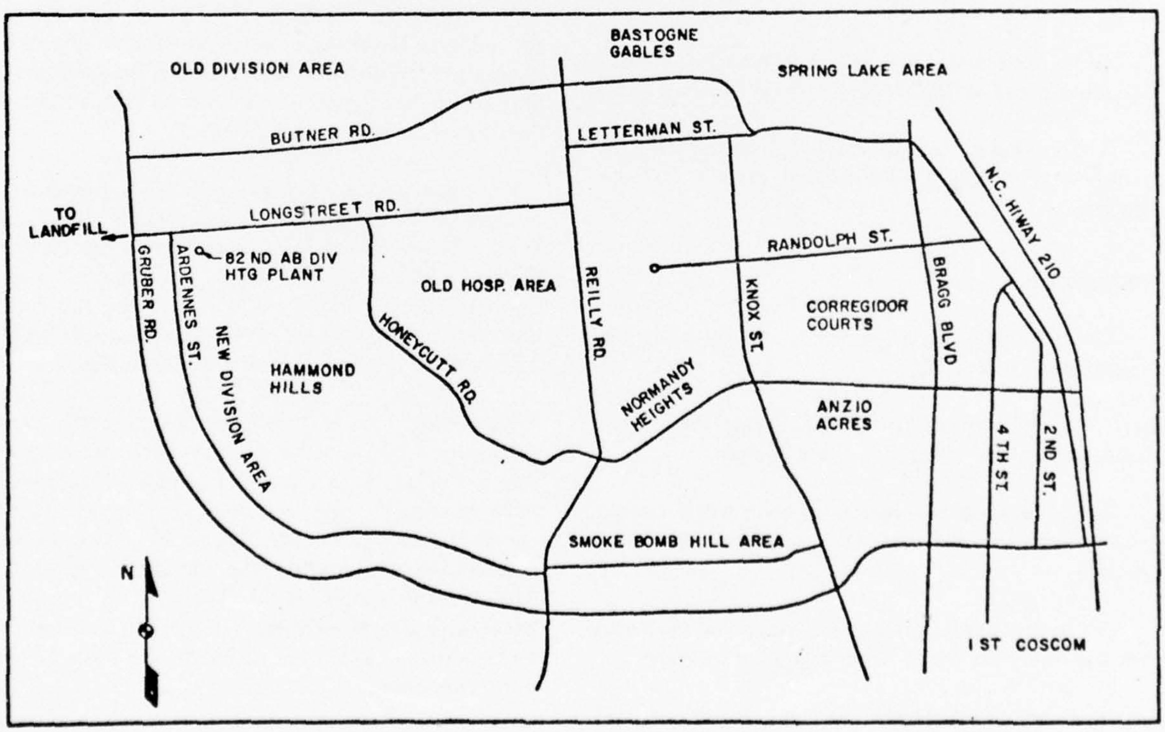


Figure 1. General location map of Ft. Bragg and surroundings.

out rapidly on large quantities of materials in a relatively simple apparatus.

An advantageous by-product of waste incineration is generation of useful heat, which can be recovered and used to supplement steam and hot water supplies. Implementing a CRE (converting refuse to energy) system can result in reduced consumption of increasingly costly conventional fuels, decreased landfill requirements, and, often, cost-saving adjustments in the waste collection/hauling system.

Recognizing the need to conserve conventional fuels, the economic advantages of current CRE systems, and the environmental advantages of solid waste reduction and sterilization by incineration, the Ft. Bragg Facilities Engineer initiated this investigation into the feasibility of energy-recovery incineration of solid waste at Ft. Bragg.

Objectives

The objectives of this study were threefold:

1. To assess the technical and economic feasibility of using refuse as an energy resource at Ft. Bragg, NC

2. To determine the most economical proven system for converting refuse to energy (CRE system)

3. To develop and provide engineering data in support of potential CRE system project development.

Approach

The approach taken in the study followed the seven steps listed below:

1. Solid waste generated at Ft. Bragg, Pope AFB, and the civilian sector was characterized.

2. Combustion parameters of each waste stream were computed and waste energy values were determined.

3. Steam supply/demand structure and electrical power requirements at Ft. Bragg were assessed.

4. A site was selected for refuse-derived fuel (RDF) processing, utilization, and heat recovery for steam production and/or electrical power.

5. Technically proven energy-recovery systems applicable to site-specific characteristics were identified.

6. Fixed (capital) and variable (annual) cost elements associated with each alternative CRE system were estimated.

7. A comparative present value economic summary of alternative CRE systems was prepared with FY81 as the project base year and a facility economic life of 25 years.

2 SUMMARY OF FINDINGS

Solid waste is generated at a rate of 135 TPD_5* (tons/day, 5-day basis) at Ft. Bragg and Pope AFB. The waste stream in the civilian sector (the city of Fayetteville and the small municipal/residential areas in Cumberland County) is generated at a rate of 465 TPD_5. The annual combined military-civilian waste stream is 155,052 TPY (Appendix A).

The energy potential of the military waste stream is 1919.0 MBtu/day, on a 5-day basis. Waste generated in the civilian sector has an energy value of 5434.0 MBtu/day, 5-day basis. The energy value of the military-Fayetteville waste stream is approximately 1422 MBtu/day, while that of the combined military-civilian waste stream is about 7306.8 MBtu/day, 5-day basis (Appendix B).

Four major heating/industrial boiler plants are operated at Ft. Bragg. The largest plant (C-1432, the 82nd Airborne Division Heating Plant) houses three boilers, each rated at 95 MBtu/hr. The plant produces 160 psig saturated steam for heating and cooling. Average daily steam production ranges between 2,630,000 lb (February) and 976,000 lb (May).

Ft. Bragg has no electrical energy production capability. Electrical power is purchased from Carolina Power and Lighting at a rate of \$0.0137/kWh. Peak demand charges for electrical power are based on the monthly 15-minute high or 90 percent of the annual high consumption rate, whichever is greatest. The demand charge is \$3.75/kW. The electrical baseload is 100 units, where 1 unit is 270 kW. Spring and summer monthly demand highs are 106 and 173 units (Appendix C).

*SI conversion factors are provided at the end of the report.

The investigation reviewed several combustion technologies for recovering energy from waste materials, including firing either processed fluff or dust RDF in existing steam generators at C-1432, use of densified RDF on a mechanical stoker in new combustion hardware, a high-temperature slag-forming incinerator, pyrolytic conversion of waste to a gaseous fuel, and conventional incineration. It was found that firing waste on a three-flight double reciprocating grate stoker in a refractory furnace with a staggered "D" type watertube heat exchanger in series could be recommended as a relatively superior system for converting waste to energy at Ft. Bragg (Appendix D).

The recommended site for the CRE facility is about 1200 ft west of C-1432 on available unoccupied land. This location allows integration of the CRE facility into existing facilities at C-1432 for steam distribution, condensate return, and boiler feedwater. It facilitates removal of ash and residue in that it is on the main route to the base sanitary landfill (Appendix E).

Two CRE scenarios were evaluated under each of three levels of waste management operations: military (Ft. Bragg and Pope AFB) alone, military-Fayetteville, and military-civilian region (including small municipal and residential areas in Cumberland County). One scenario treated production of medium-pressure steam for heating and cooling. The second scenario included production of steam for heating and cooling, with generation of high-pressure steam for electrical power generation occurring 5 months of the year (Appendix F).

The most cost-effective system is one in which solid waste generated in the military sector and at Fayetteville is used to generate 160-psig saturated steam in a new CRE facility near C-1432 at Ft. Bragg. The process flow includes weighing waste deliveries on a standard platform scale, delivery on a tipping floor, moving by front-end loader, coarse shredding, removal of ferrous metals, temporary storage, combustion on a mechanical stoker in a refractory furnace, heat recovery in a watertube boiler, cleaning of off-gases, and quenching of bottom ash. The system will allow shutdown of C-1432 for 5 months of the year and will conserve 3.1 million gal of fuel oil annually. A capital investment of $6.8 million (FY81 dollars) is required. Annual 25-year present value (PV) costs are an effective savings of $17.3 million, and the total PV system cost is an effective savings of $10.5 million (FY81 dollars). The savings/investment ratio is 3.74/1.00, and the payback period is 2.91 years. If the civilian sector elects not to participate in such an effort, a similar system scaled to use military waste alone is cost-effective (Appendix F).

3 CONCLUSIONS

Use of refuse as an energy resource at Ft. Bragg is technically and economically feasible.

The most cost-effective CRE system, Scenario 2A (analyzed in Appendices F and G), has the following major elements:

1. Solid waste from the City of Fayetteville, Ft. Bragg, and Pope AFB is delivered to and weighed at a CRE plant near the 82nd Airborne Division Heating Plant at Ft. Bragg.

2. Delivered solid waste is moved by front-end loader from the tipping floor to a pit conveyor which moves it to a shredder. The shredded fraction moves through a magnetic pulley separator for removal and recovery of ferrous metals. The shredded fraction is then conveyed to a storage hopper.

3. RDF is moved from the storage hopper by screw conveyor to the incinerator feed hopper.

4. RDF is hydraulically ram-fed to the furnace. The stoking mechanism is a three-flight, double reciprocating grate. Ash falls to a quench tank and is conveyed to nearby containers for disposal.

5. Gaseous combustion products are drawn through an afterburning section, a watertube boiler, and air pollution control apparatus, and pass through a stack to the atmosphere.

6. Steam produced at the CRE plant is run to the existing main header at the nearby 82nd Airborne Division Heating Plant for distribution. Saturated steam at 160 psig is produced. Condensate is returned to the 82nd Airborne Division Heating Plant, makeup added, and treated boiler feedwater delivered for use at the new CRE facility.

By implementing the system, Ft. Bragg will be able to conserve about 3.1 million gal of fuel oil annually and completely shut down the adjacent heating plant 5 or 6 months of the year. A capital investment of $6.8 million is required (FY81 dollars).

Present value total system costs are an effective savings of $10.5 million. On a 25-year life-cycle basis, the savings/investment ratio is 3.64/1.0.

The system requires that the City of Fayetteville deliver mixed solid waste (devoid of large incombustibles and hazardous and particularly obnoxious materials) to the Ft. Bragg CRE plant. No cost is accrued to the civilian waste management operation other than through minor increases in haul distance. Should any transfer station be required in the civilian sector, it should be built and operated at civilian expense.

If the City of Fayetteville does not elect to participate, refuse generated only at Ft. Bragg and Pope AFB can still be economically used as an energy resource in a system resembling the most cost-effective one, but smaller in scale (described in Appendix F). An investment of $5.3 million is required (FY81 dollars). Present value total system costs are an effective savings of $6.3 million.

4 RECOMMENDATIONS

It is recommended that Ft. Bragg approach the City of Fayetteville with a waste management plan proposal based on the CRE system found to be most cost-effective in this investigation.

If the civilian sector does not choose to participate in a cooperative waste management plan, it is recommended that Ft. Bragg take the steps necessary to implement the CRE system based on military waste alone which is technically described in this report.

APPENDIX A:

SOLID WASTE CHARACTERIZATION

General

This appendix summarizes that portion of the study which characterized solid waste generated in the military sector (Ft. Bragg and Pope AFB) and the civilian sector (City of Fayetteville and Cumberland County). Solid waste is generated at a rate of about 135 TPD_5 at Ft. Bragg and Pope AFB together, and 465 TPD_5 in the civilian sector.

Military Solid Waste

A 15-day weigh survey was conducted at the Ft. Bragg sanitary landfill from 10 to 28 March 1975. Collection vehicles delivering solid waste to the landfill from Ft. Bragg and Pope AFB were weighed on General Electrodynamics Model MD400 portable hydraulic scales provided by the U.S. Army Construction Engineering Research Laboratory (CERL); the survey was directed by the Ft. Bragg Facilities Engineer. This survey revealed that an average of 131.9 TPD_5 solid waste is generated at Ft. Bragg and 3.3 TPD_5 at Pope AFB.

CERL conducted site surveys to determine the constituency of solid waste delivered to the Ft. Bragg landfill. Table A1 gives the constituency of landfilled waste generated at both Ft. Bragg and Pope AFB. Because of the brevity of the waste survey, the constituencies given in Table A1 are to be considered only general, but of sufficient accuracy to support a feasibility study. Observations at the landfill revealed that over-size bulky wastes such as appliances, pallets, and construction/demolition debris are generated infrequently and in comparatively small quantities. Much of the wood generated is large (bracing, pallets, dunnage). Wastes classified as "Other" in Table A1 include oil and paint cans, rags, drums, cable, wire, and similar miscellaneous materials.

Civilian Solid Waste

Data pertaining to the rate of solid waste generation in the civilian sector were provided by appropriate civilian authorities to the Ft. Bragg Facilities Engineer, who transmitted the information to CERL for use in the feasibility study.

The log of daily solid waste volume deliveries to the Fayetteville municipal landfill indicates that an average of 4,500 cu yd of solid waste is generated every 6 days in the City of Fayetteville. Applying a solid waste emission factor of 3 lb/person/day[2] to the population of 51,500[3] results in a solid waste mass generation rate of 108 TPD_5 for Fayetteville. Additional computation reveals a solid waste density of 288 lb/cu yd, which compares to published figures for national average mixed municipal/residential solid waste densities (mix of compacted and uncompacted).[4] To facilitate the feasibility study, it was assumed that solid waste generated at Fayetteville compares to the average national refuse composition given in Table A2. Table A3 gives a general description of each constituent.

Table A1

Ft. Bragg: Constituency of Solid Waste at Landfill*

Constituent	Weight Percent
Paper and cardboard	55.2
Garbage	12.1
Plastic (materials, packaging)	10.8
Wood	9.1
Misc.	5.9
Metals	3.2
Glass/ceramics	1.9
Vegetation	0.8
Inerts	0.8
Leather	0.1
Rubber	0.1
TOTAL	100.0

*Ft. Bragg and Pope AFB aggregate waste stream 135.2 TPD_5.

Table A2

National Average Solid Waste Composition*

Constituent	Weight Percent
Paper and cardboard	50.7
Food waste (garbage)	19.1
Metals	10.0
Glass	9.7
Wood	2.9
Textiles	2.6
Leather and rubber	1.9
Miscellaneous	1.7
Plastics	1.4
TOTAL	100.0

*Reprinted with permission of the American Society of Mechanical Engineers. From W. R. Niessen and S. H. Chansky, "The Nature of Refuse," *Proceedings of 1970 Incinerator Conference*, 1970.

[2]Emission factor from *NCRR Bulletin* (Spring 1973).

[3]*National Atlas of the United States* (U.S. Geological Survey, 1970).

[4]*Incineration Standards* (Incinerator Institute of America, 1970).

Table A3

Description of National Average Solid Waste Characteristics*

Constituent	Description
Paper and cardboard	Various types, some with fillers, Packaging
Food waste	Garbage
Metals	Cans, wire, foil
Glass	Primarily bottles
Wood	Packaging, furniture, logs, twigs
Textiles	Cellulosic, protein, woven synthetics
Leather and rubber	Shoes, tires, toys
Misc.	Inorganic ash, stones, dust
Plastics	Polyvinyl chloride, polyethylene; Styrene, in packaging, housewares, furniture, toys and nonwoven synthetics

*Reprinted with permission of the American Society of Mechanical Engineers. From W. R. Niessen and S. H. Chansky, "The Nature of Refuse," *Proceedings of 1970 Incinerator Conference*, 1970.

A 14-day waste survey conducted at the county landfill (Cliffdale landfill, run by Cumberland County Department of Public Health) from 7 through 20 July 1975 showed that an average of 5.128 cu yd/day (5-day basis) of solid waste is generated within Cumberland County (excluding Fayetteville and Ft. Bragg). Applying a solid waste emission factor of 3 lb/person/day[5] to the population of 170,000 (County less Fayetteville),[6] results in a computed solid waste mass generation rate of 357 TPD_5 for Cumberland County. Additional computation reveals a solid waste density of 139 lb/cu yd, which compares to loose bulk densities shown to exist elsewhere for solid waste generated in rural residential areas.[7] To facilitate the feasibility study, it was assumed that solid waste generated in Cumberland County compares to average national refuse composition given in Table A2.

[5]Emission factor from *NCRR Bulletin* (Spring 1973).

[6]*National Atlas of the United States.*

[7]S. A. Hathaway and J. P. Woodyard, *Technical Evaluation Study: Energy-Recovery Utilization of Waste at Puget Sound Naval Shipyard, Bremerton, WA*, Technical Report E-89 (U.S. Army Construction Engineering Research Laboratory [CERL], 1976).

Summary of Solid Waste Characterization

Tables A4 and A5 summarize the characteristics of the military and civilian solid waste streams, respectively. The combined military-civilian solid waste stream is 156,052 TPY, or about 600 TPD_5.

Table A4

Ft. Bragg: Summary of Military Solid Waste Characterization*

Constituent	Weight Percent	Generation Rate TPD_5	Generation Rate TPY
Paper and cardboard	55.2	74.6	19,396
Garbage	12.1	16.4	4,264
Plastics	10.8	14.6	3,796
Wood	9.1	12.3	3,198
Miscellaneous	5.9	7.9	2,054
Metals	3.2	4.3	1,118
Glass/ceramics	1.9	2.6	676
Vegetation	0.8	1.1	286
Inerts	0.8	1.1	286
Leather	0.1	0.15	39
Rubber	0.1	0.15	39
TOTAL	100.0	135.2	35,152

*Ft. Bragg and Pope AFB aggregate waste stream.

Table A5

Ft. Bragg: Summary of Civilian Solid Waste Characterization*

Constituent	Weight Percent	Generation Rate TPD_5	Generation Rate TPY
Paper and cardboard	50.7	235.8	61,308
Food waste (garbage)	19.1	88.8	23,088
Metals	10.0	46.5	12,090
Glass	9.7	45.1	11,726
Wood	2.9	13.5	3,510
Textiles	2.6	12.1	3,146
Leather and rubber	1.9	8.8	2,288
Miscellaneous	1.7	7.9	2,054
Plastics	1.4	6.5	1,690
TOTAL	100.0	465.0	120,900

*City of Fayetteville and Cumberland County.

APPENDIX B:

WASTE STREAM COMBUSTION PARAMETERS

General

This appendix summarizes computations performed to determine higher and lower heating values, and volatile, fixed carbon, moisture and ash content of the military and civilian solid waste streams. Computations are given for the waste streams individually and in combination. Computations were also made to determine potential energy available to an energy-recovery incineration system based on individual and combined waste streams. The energy potential of the military and civilian waste streams is 1919 MBtu/day and 5434 MBtu/day, respectively. The energy potential of the combined military-civilian waste stream is about 7307 MBtu/day.

Combustion Parameters: Military Solid Waste Stream

Table B1 summarizes computations made to determine waste fuel characteristics of solid waste generated at Ft. Bragg and Pope AFB.

Combustion Parameters: Civilian Solid Waste Stream

Table B2 summarizes computations made to determine waste fuel characteristics of solid waste generated at Fayetteville and Cumberland County.

Combustion Parameters: Combined Military/Civilian Solid Waste Stream

Table B3 summarizes computations made to determine waste fuel characteristics of the combined solid waste stream from military (Ft. Bragg and Pope AFB) and civilian (Fayetteville and Cumberland County) sources.

Summary of Solid Waste Stream Energy Potential

Table B4 summarizes combustion parameters computed in Tables B1, B2, and B3 for solid waste generated at military and civilian sources. Table B5 summarizes computations made to determine the energy potential of the individual and combined military/civilian solid waste streams. The figures in Table B5 do not account for efficiencies of individual energy-recovery technologies, which are considered in Appendix D, nor do they represent energy-recovery system design quantities, which normally are determined by increasing the values by 25 percent. Design computations are presented in Appendix D.

Table B1

Ft. Bragg: Computation of Combustion Parameters of Military Solid Waste

Constituent	Weight Percent	% Moisture	% Volatiles	% Fixed Carbon	% Ash	Heating Value (Btu/lb) Lower	Heating Value (Btu/lb) Higher
Paper and cardboard	52.2	4.99	72.12	9.22	6.67	7,443	7,830
Garbage	12.1	48.93	46.91	2.93	1.23	6,898	11,298
Plastics	10.8	1.00	91.00	7.00	1.00	13,000	15,910
Wood	9.1	10.00	69.00	18.00	3.00	4,779	9,000
Metals	3.2	0.10	0.10	0.10	99.70	1	1
Glass/ceramics	1.9	0.10	0.10	0.10	99.70	1	1
Inerts	0.8	—	—	—	100.00	—	—
Leather	0.1	4.31	62.08	8.17	25.44	9,071	9,426
Rubber	0.1	0.10	66.90	8.00	25.00	10,500	15,000
Composite	100.0	11.9	69.0	8.2	10.9	7,079	8,034

Table B2

Ft. Bragg: Computation of Combustion Parameters of Civilian Solid Waste

Constituent	Weight Percent	% Moisture	% Volatiles	% Fixed Carbon	% Ash	Heating Value (Btu/lb) Lower	Higher
Paper and cardboard	50.7	4.99	79.12	9.22	6.67	7,443	7,830
Food waste (garbage)	19.1	48.93	46.91	2.93	1.23	6,898	11,298
Metals	10.0	0.10	0.10	0.10	99.70	1	1
Glass	9.7	0.10	0.10	0.10	99.70	1	1
Wood	2.9	10.00	69.00	18.00	3.00	4,779	9,000
Textiles	2.6	3.00	89.50	6.50	1.00	6,500	6,780
Leather and rubber	1.9	2.21	64.49	8.09	25.21	9,785	12,213
Miscellaneous	1.7	29.97	52.49	5.23	12.31	4,500	7,500
Plastics	1.4	1.00	91.00	7.00	1.00	13,000	15,910
Composite	100.0	12.8	56.8	6.3	24.1	5,843	7,147

Table B3

Ft. Bragg: Computation of Combustion Parameters of Combined Military/Civilian Solid Waste

Constituent	Weight Percent	% Moisture	% Volatiles	% Fixed Carbon	% Ash	Heating Value (Btu/lb) Lower	Higher
Paper and cardboard	52.9	4.99	79.12	9.22	6.67	7,443	7,830
Garbage	17.9	48.93	46.91	2.93	1.23	6,898	11,298
Metals	8.6	0.10	0.10	0.10	99.70	1	1
Glass/ceramics	8.2	0.10	0.10	0.10	99.70	1	1
Wood	4.3	10.00	69.00	18.00	3.00	4,779	7,500
Miscellaneous*	3.7	22.65	49.82	5.19	22.34	4,400	7,300
Plastics	3.6	1.00	91.00	7.00	1.00	13,000	15,910
Leather and rubber	0.8	2.21	64.49	8.09	25.21	9,785	12,213
Composite	100.0	12.8	58.9	6.8	21.5	6,087	7,428

*Includes textiles, vegetation, inerts.

Table B4

Ft. Bragg: Summary of Combustion Parameters of Individual and Combined Military/Civilian Solid Waste

Waste Stream	% Moisture	% Volatiles	% Fixed Carbon	% Ash	Heating Value (Btu/lb) Lower	Higher
Military	11.9	69.0	8.2	10.9	7,097	8,034
All civilian	12.8	56.8	6.3	24.1	5,843	7,147
Military-Fayetteville*	12.4	63.5	7.9	16.2	6,583	7,731
Military-all civilian	12.8	58.9	6.8	21.5	6,087	7,428

*Values are weighted averages.

Table B5

Ft. Bragg: Summary of Solid Waste Stream Energy Potential

Waste Stream	Generation Rate (TPD_5)	Lower Heating Value (Btu/lb)	Waste Energy Potential (10^6 Btu/day)	Unadjusted Fuel Oil Equivalent (gal/yr)
Military	135.2	7,097	1919.0	3,326,317
All civilian	465.0	5,843	5434.0	9,418,916
Military-Fayetteville	108.0	6,583	1421.9	2,464,675
Military-all civilian	600.2	6,087	7306.8*	12,665,180*

*Error due to rounding procedure throughout calculation method.

APPENDIX C:

STEAM AND ELECTRICAL POWER SUPPLY/DEMAND STRUCTURE

General

This appendix summarizes findings pertaining to steam production capabilities and steam and electrical power requirements at Ft. Bragg.

Steam Production Capabilities

Four major heating/industrial boiler plants are operated at Ft. Bragg. Table C1 summarizes general data pertaining to the major boiler plants. The largest plant is C-1432, the 82nd Airborne Division Heating Plant. For reasons stated in Appendix E, C-1432 is the recommended location for an energy-recovery facility. C-1432 houses three Erie City two-drum, waterwall watertube boilers each rated at 95 MBtu/hr output. The boilers were erected in 1953 and designed to fire Eastern bituminous coal by spreader stoker (overfed chain grate). Approximately 10 years ago, the boilers were converted to fire natural gas and fuel oil. There is limited capability at C-1432 to reconvert to solid fuel. Reconversion to solid fuel would require additional operating labor, restoration or procurement of nearly all necessary coal firing/handling equipment, and addition of retrofitted air pollution control equipment. Reconversion to coal firing at C-1432 requires minimally 18 months and an estimated cost of $1,500,000.

The Laundry Boiler Plant (2-5411) has three boilers; two boilers are field-erected waterwall watertube units designed to burn coal, and the third is a gas-fired package unit. The plant produces low pressure saturated steam for use in the laundry. As in the case of C-1432, this plant cannot be converted to fire waste fuel without comprehensive and costly hardware modifications.

The remaining heating and industrial plants at Ft. Bragg (4-3124, D-3529) house small-capacity package boilers which are not candidate for supplemental waste fuel firing.

Steam Production Structure

Tables C2 and C3 summarize the monthly total steam production for C-1432 and 2-5411, respectively, for calendar year 74, a representative year. Implementation of absorption chillers at Ft. Bragg is expected to increase steam demand from C-1432 by approximately 15 percent during the warm season. Adjusted steam production figures for C-1432 based on the 15 percent warm season increase are given in Table C4. Steam production for the transitional months of April and October was adjusted by 10 percent, while production for remaining warm season months was adjusted by 15 percent.

Electrical Power Requirements

Ft. Bragg does not have the capability to generate electrical power. This utility is purchased from Caro-

Table C1

General Information: Major Heating and Industrial Plants at Ft. Bragg

Item	Plant/Building Number C-1432	4-3124	D-3529	2-5411
Number of buildings served	169	139	88	3
Area of buildings served (000 sq ft)	2901	858	1664	63
Number of boilers	3	3	4	3
Boiler size (MBtu/hr)	(3) 95	(3) 38	(4) 26	(1) 25, (1) 38, (1) 17
Boiler type (P = package, F = field erec.)	F	(2) P, (1) F	F	(2) F, (1) P
Primary fuel	coal	(2) gas, (1) coal	gas	(2) coal, (1) gas
Present fuel	gas	gas	gas	(2) gas, (1) coal
Alternate fuel	oil	oil	oil	oil
6-mos coal conversion capability	no	no	no	no
Added pollution control to burn coal	yes	yes	yes	yes
Low sulfur coal available	yes	yes	yes	yes
Long-term coal conversion capability	18 mos	(1) 12 mos	no	(1) 12 mos
Current annual fuel consumption				
Oil (M gal)	0.5	0.2	0.2	0.2
Gas (M cu ft)	642.0	235.0	160.0	125.0
Coal (Est. ktons)	28.5	10.2	7.2	5.8

lina Power and Lighting. Baseload power demand is 100 units (1 unit equals 270 kW). Peak demand occurs in the spring and summer months, with average highs of 106 and 173 units, respectively. Baseload power charges are $0.0137/kWh. Peak demand charge is $3.75/kW, and is based on the monthly 15-minute high demand rate or 90 percent of the annual high, whichever is greater. It is anticipated that the annual cost of electrical power to Ft. Bragg will continue to rise in response to general demand growth on the installation and the increasing cost of fossil fuels to the utility.

Table C2

Steam Production Summary for Heating and Industrial Plant C-1432 at Ft. Bragg, 1974

		Steam Production (klb)*		
Month	*Monthly Total*	*Minimum Day*	*Maximum Day*	*Average Day*
January	75,052	1826	2931	2421
February	73,648	2368	3033	2630
March	73,207	1859	2705	2361
April	43,183	950	2203	1439
May	30,266	420	1434	976
June	30,958	642	1308	1032
July	33,087	669	1218	1067
August	37,611	914	1575	1213
September	30,899	635	1786	1030
October	35,362	654	2091	1411
November	59,458	1324	2437	1982
December	71,858	2111	2544	2318

*Steam 160 psig saturated.
Feedwater 220°F at 4 lb.
Average: 66,400 lb/hr over 3-yr period.

Table C3

Steam Production Summary for Heating and Industrial Plant 2-5411 at Ft. Bragg, 1974

		Steam Production (klb)*		
Month	**Monthly Total**	**Minimum Day**	**Maximum Day**	**Average Day**
January	5525	151	375	240
February	4871	147	334	232
March	4640	140	269	211
April	3031	384	1550	1010
May	3576	61	237	242
June	3171	82	169	144
July	3231	83	166	140
August	2810	96	163	127
September	2708	88	152	135
October	3789	133	224	180
November	3958	145	241	198
December	4377	145	244	208

*Steam 125 psig saturated.
Feedwater 220°F at 160 psig.

Table C4

Expected Monthly and Hourly Steam Demand for C-1432 at Ft. Bragg*

	Steam Production (klb)**	
Month	**Monthly Total**	**Average Hourly**
January	75,052	100,876
February	73,648	109,595
March	73,207	98,397
April	47,501	65,974
May	34,805	46,781
June	35,601	49,445
July	38,050	51,142
August	43,252	58,134
September	35,533	49,351
October	38,898	52,282
November	59,458	82,581
December	71,858	96,583

*Adjusted for increased steam consumption by new chillers.
**Steam 160 psig saturated; feedwater 200°F at 4 lb.

APPENDIX D:

DETERMINATION OF RECOMMENDED COMBUSTION SYSTEM

General

This appendix summarizes findings pertaining to identification of proven systems for converting refuse to energy at Ft. Bragg. Three general waste management scenarios were found to be possible: military (Ft. Bragg and Pope AFB) alone, military-Fayetteville, and military-Fayetteville/Cumberland County. This part of the investigation focused on developing a recommended CRE system design concept for each waste management scenario.

Basic Design Concept Requirements

The following requirements guided development of a CRE system design concept for each waste management scenario:[8]

1. Dependability. The degree to which a design follows a prior proven art, the potential of the designed system to withstand predictable wear, and the degree of the system's complexity which would make its proper performance contingent on highly skilled personnel.

2. Experience. The combined utilization of similar equipment for combustion/incineration of solid waste.

3. Conservation. The consumption of material or energy which must be provided from external or virgin sources.

4. Environment. Impact of system and facility on immediate environment (atmospheric, land, and water resources).

5. Economics. Combined analysis of capital and operational costs.

6. Operation and Maintenance. Ease and intensity of daily operation, preventive routine and cyclical maintenance requirements, procurement and installation of replacement parts.

[8] *Phase I Feasibility Study: Refuse Incinerator/Heat Reclamation Boiler Facility, Naval Station Mayport, Florida* (Greenleaf/Telesca, Inc., December 1975).

Package CRE Systems

Package CRE systems of the types reviewed in Appendix H were found to be inapplicable. The largest proven package incinerator currently available has a waste input capacity of approximately 19 MBtu/hr. Applying package incinerators to the military waste stream alone (1919 MBtu/day, Table B5) would require minimally five units operating 24 hr/day. To provide proper redundancy in a package-base system would require at least an additional three units. It was judged that operating and maintaining a battery of eight package incinerators would be so unnecessarily costly and cumbersome as to warrant no further consideration.

Identification of Field-Erected CRE Systems

The investigation revealed six field-erected CRE systems for possible application at Ft. Bragg. Each system can be designed to accommodate the quantities of waste to be incinerated under each of the waste management scenarios treated in the study. The alternatives are:

1. Conventional inclined grate (stoker) incinerator

2. Reilly slag-forming incinerator

3. Firing densified refuse-derived fuel (DRDF) on moving grate in existing boilers

4. Suspension-firing fluff RDF in existing boilers

5. Suspension-firing dust RDF in existing boilers

6. Pyrolysis.

Description of Field-Erected CRE Systems

Conventional Inclined Grate (Stoker) Incinerator

Incineration of municipal solid waste in conventional inclined grate incinerators has a long and well-established history of success. Somewhat typical of these types are two 225-TPD incinerator installations at Ft. Lauderdale, FL, and the Northeast incinerator in Dade County, FL, rated 300 TPD. These incinerators have capacities within the range of quantities of solid waste to be burned under each waste management scenario. A typical section of a refractory lined incinerator is shown in Figure D1. A hydraulically operated ram feeder introduces refuse

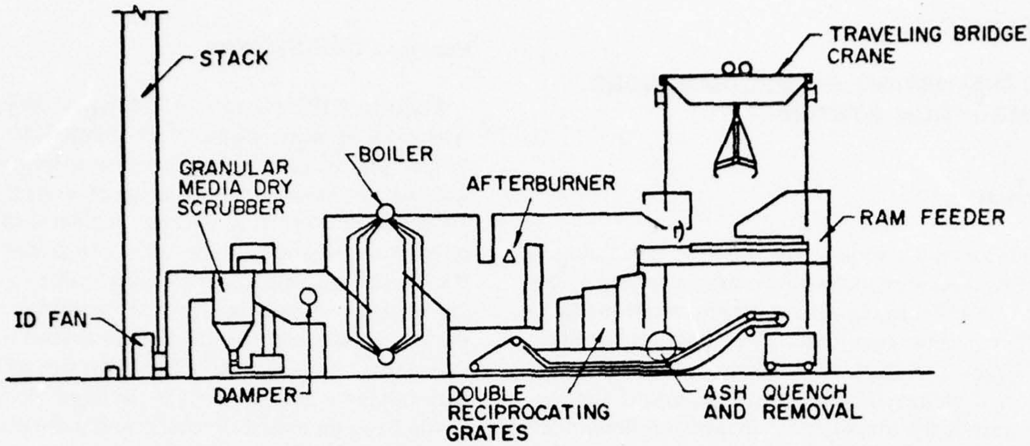


Figure D1. Conventional incinerator.

into the primary combustion zone where it falls onto an agitated grate. The feeder has an adjustable rate and effectively meters a known amount of refuse per unit time into the furnace. The recommended grate is the double reciprocating stoker (Figure D2) which effectively controls the distribution of refuse in the primary combustion zone.[9] Efficient combustion control is achieved by modulating underfire and overfire air. An afterburner is provided to burn combustibles remaining in the furnace gas stream. Hot gases then pass to the boiler section.

[9]*Conversion of Central Heating Plant Boilers to Refuse Derived Fuel Firing* (Department of the Army, New York District, Corps of Engineers, 1975).

Reilly Slag Forming Incinerator[10]

A new furnace concept illustrated by Figure D3 was considered. The two-stage slag-forming refuse incinerator furnace uses excess combustion air to hold the furnace temperature below the slag-forming limit of about 1,800°F. The slagging chamber uses part of the hot, oxygen-rich flue gas from the conventional furnace to incinerate the final 20 to 40 percent of the combustible refuse.

[10]*Phase I Feasibility Study: Refuse Incinerator/Heat Reclamation Boiler Facility at Naval Station Mayport, FL* (Greenleaf/Telesca, Inc., 1975).

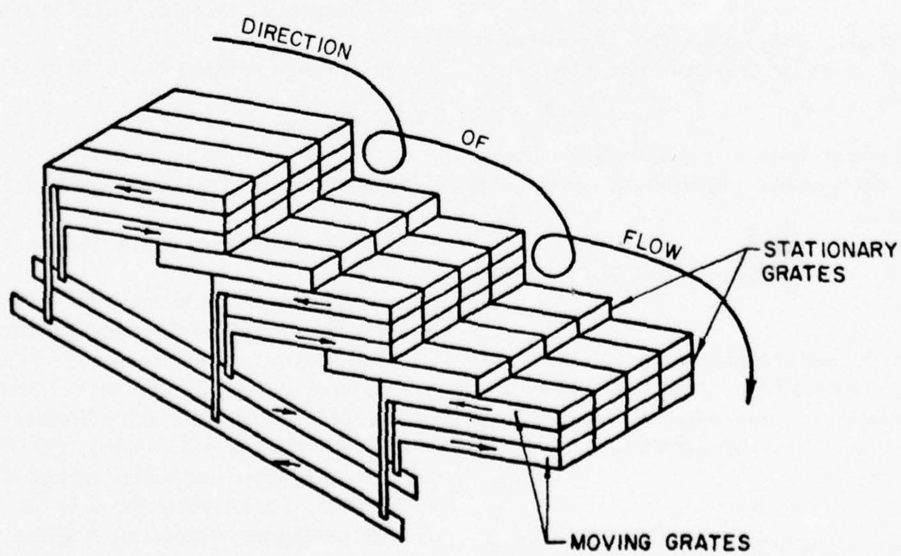


Figure D2. Double reciprocating grate stoker.

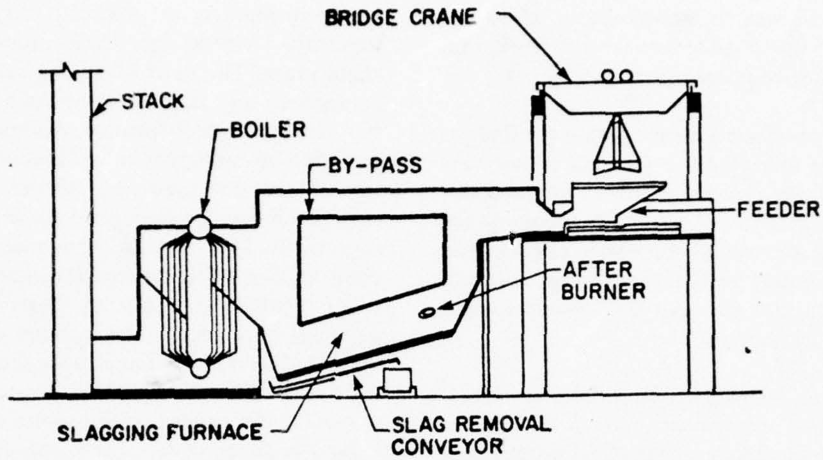


Figure D3. Reilly slag-forming incinerator.

The first stage furnace chamber, which is identified as the "primary furnace," is smaller than that in conventional incinerators. The short, inclined grate allows only 60 to 80 percent completion of burning of the combustible refuse introduced to the furnace. The unburned refuse and other solid residue from the primary furnace fall from the primary grate to the "slagging furnace" below, where combustion continues.

The primary furnace feed system, temperature control system, and general design are identical to those of present plants which have been in successful operation for 3 years or longer. The ram feeder meters refuse from a storage hopper at a controlled rate into the furnace, where it is aerated with high pressure jets and tumbled to a reciprocating grate. Combustion air is provided by two forced draft fans. One fan supplies the undergrate air requirement while the other provides air to a series of overfire jets. The overfire jets not only provide the turbulence essential to good combustion, but also dilute and cool the furnace gases to prevent overheating the primary furnace. The dilution effect, which is automatically regulated to maintain a uniform primary furnace temperature, provides an oxygen ratio of about 11 percent in the furnace exit gas when furnace temperature is maintained at 1,800°F. This figure varies slightly (depending on the moisture content of the refuse) from 11.8 percent for 25 percent refuse moisture to 10.7 percent for 40 percent refuse moisture.

The flue gas from the primary furnace divides to flow either through the slagging furnace or through a damper-regulated bypass breeching. The bypass damper is water-cooled and refractory-encased to withstand the 1,800°F flue gas. Since all flue gas from the primary furnace must go through one of the two passages, closing down the bypass damper increases the gas flow through the slagging furnace, while opening it decreases the slagging furnace gas flow.

The slagging furnace is thus fed with hot, partially combusted refuse and hot (1,800°F) oxygen-laden flue gas which combine to release additional heat. The design of the process is aimed at accomplishing three functions:

1. Provide the extended residence time required to complete combustion of the refuse which was not consumed in the primary furnace.

2. Provide a temperature-resistant enclosure which is not only insulated from outside atmospheric temperatures, but is also shielded to minimize radiation losses from the slagging furnace to the primary furnace and connecting flues.

3. Provide sufficient gradient to the furnace hearth that the molten residue and ash will flow to the exit port and into the quench tank.

The primary furnace, as noted earlier, is undersized in comparison to conventional incinerator furnaces so that the existence of carbon monoxide and the presence of excess air are distinct probabilities at the primary furnace exit. The extensive residence of the flue gas at high temperature levels in the slagging furnace and connecting passages assures the ultimate conversion of carbon monoxide to carbon

dioxide. Such conversion would make additional heat available to the slagging furnace and further increase the latitude of operation.

The processes indicated for conveying the flue gas and slag residue following the slagging furnace are conventional, tested procedures which are presently in use in operating plants. A rugged drag conveyor in the quench tank removes all of the solid residue from the process, including grate siftings, slag, and particulate from the flue gas. No further air-cleaning requirement is anticipated.

Although this incinerator uses "conventional" refuse incinerator equipment and processes and offers minimal secondary application problems, a slagging furnace installation does not now exist. However, due to the potential of the system, it was considered in the evaluation.

Densified RDF

Use of densified (pelletized) RDF on a traveling grate was evaluated. Densified RDF is produced by passing the shredded light fraction of mixed solid waste through a mechanical extrusion device (pelletizer) (Figure D4). Long-term use of densified RDF (DRDF) has not yet been proven, although successful demonstrations have taken place at Eugene, OR, Chanute AFB, IL, and Wright-Patterson AFB, OH. The demonstration conducted by CERL at Chanute AFB in September-October 1975 showed that DRDF can be successfully co-fired with coal in a waterwall watertube boiler equipped with an overfed traveling chain grate. The optimal mixing ratio of DRDF is between 10 and 20 percent by heat release rate. It was also shown that further development of DRDF systems is required to reliably (1) control pellet moisture content and proneness to structural deterioration, (2) eliminate aluminum container pull tabs and injection-molded plastics, which can cause equipment and/or pellet structural failure, and (3) develop handling and mixing systems. Several approaches have been taken in attempts to eliminate these problems, including development of wet-pulping systems to produce DRDF. However, at the current state of the art, DRDF systems cannot be guaranteed as dependable, proven energy conservation/waste disposal measures.

Suspension-Firing Fluff RDF

Fluff RDF is the shredded and air-classified light fraction of mixed solid waste (Figure D4). The material has been successfully co-fired with pulverized coal at a mixing ratio between 10 and 20 percent RDF in Union Electric Company's power (utility) boilers at the St. Louis Meramec Plant. Fluff RDF is pneumatically fired tangentially in the furnace through burners located between coal burners in each of four corners of the furnace. While experience with this system has been marked by only moderate operational problems, most of which have now been solved, extrapolations to systems firing 100 percent

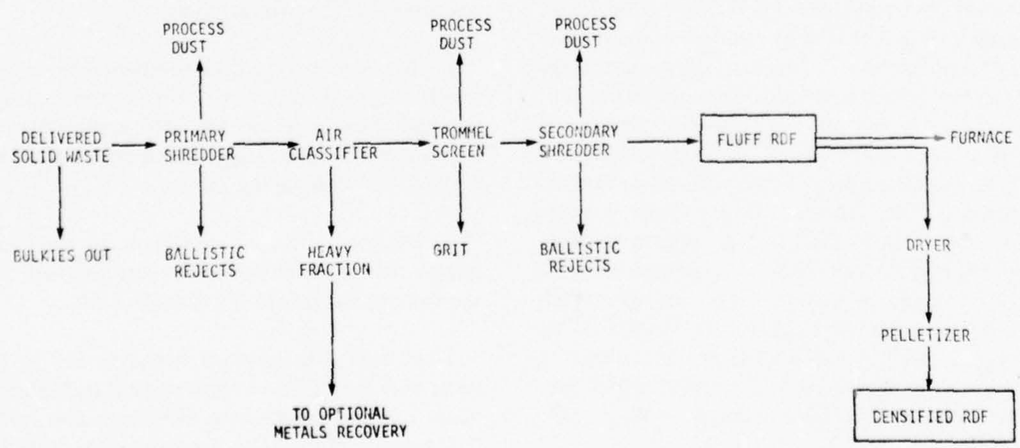


Figure D4. Process flow for production of fluff and densified RDF.

fluff RDF cannot be made easily. Since no existing system uses 100 percent fluff RDF to produce steam, such systems are considered still in the developmental stage and, therefore, cannot be guaranteed as dependable, proven energy conservation/waste disposal measures.

Suspension-Firing Dust RDF

Dust RDF is essentially an embrittled, pulverized form of fluff RDF (Figure D5). On-going research and development focuses on improved dust RDF production systems, pneumatic firing methods, and the solid in suspension with conventional fuel oil. There is currently no continuously on-line industrial or utility-scale boiler firing dust RDF. Dust RDF systems are still in the developmental stage and, therefore, cannot be guaranteed as dependable, proven energy conservation/waste disposal measures.

Pyrolysis

Several solid waste pyrolysis systems have been conceived which work on a similar principle: solid waste is fed to a chamber where it is heated to high temperatures in an oxygen-lean environment, and hydrocarbon-rich off-gases are completely combusted in a boiler. The advantages of pyrolysis are the relative ease of distributing the "fuel" (energy-rich off-gases) to users through conventional gas lines and the sterility of the quenched slag. However, the energy conversion efficiency of current pyrolysis units is comparatively low. Moreover, there is currently no continuously operating solid waste pyrolysis unit within the United States with sufficient dependability to warrant recommending the process as a reliable energy conservation/waste disposal measure.

Selection of Field-Erected CRE Systems

The investigation reviewed each potential CRE system against the basic design concept requirements set forth earlier in this section. A comparative rating system[11] in which each CRE system was scored on a point scale of 1 to 4 (best to poorest) with a line total of 15 points possible (with the exceptions of "experience" and "power usage") was used. The ratings, shown in Table D1, indicate that the conventional refractory lined furnace design is the relatively superior and, therefore, preferred combustion system.

[11]Adapted from rating system used in *Phase I Feasibility Study: Refuse Incinerator/Heat Reclamation Boiler Facility at Naval Station Mayport, FL* (Greenleaf/Telesca, Inc., 1975).

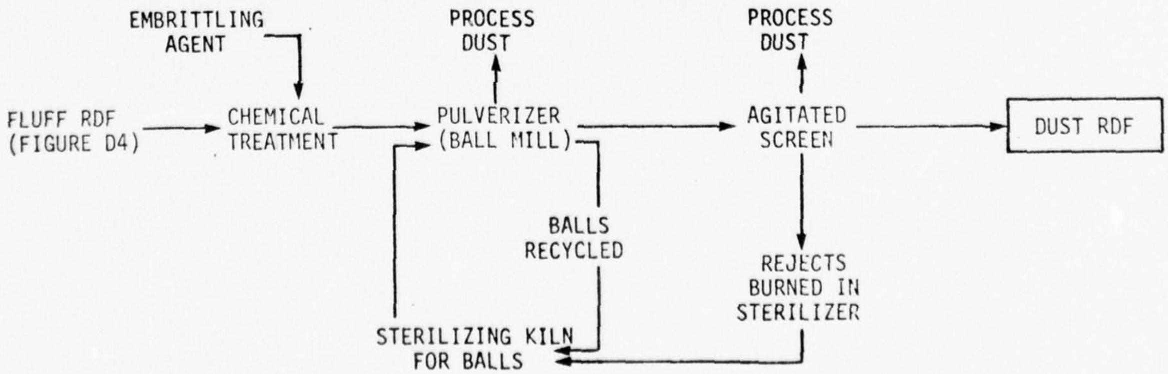


Figure D5. Process flow for production of dust RDF.

Table D1

Ft. Bragg: Comparative Ratings of Alternative CRE Systems

	Alternative* 1	2	3	4	5	6
Economics						
Capital cost	1.5	2.0	1.5	3.0	3.0	4.0
Operating cost	2.0	2.5	2.0	2.5	2.0	4.0
Score	3.5	4.5	3.5	5.5	5.0	8.0
Environment						
Air	3.5	2.5	1.5	3.0	2.0	2.5
Water	2.5	2.5	2.5	2.5	2.5	2.5
Land	3.5	3.0	1.0	3.0	1.5	3.0
Score	9.5	8.0	5.0	8.5	6.0	8.0
Dependability						
Prior art	1.5	2.5	3.0	2.5	2.5	3.0
Predictable wear	2.0	3.0	1.5	3.5	1.5	3.5
Complexity	2.0	3.0	1.0	3.0	2.5	3.5
Score	5.5	8.5	5.5	9.0	6.5	10.0
Experience						
No. of installations	1.0	3.5	4.0	4.0	3.5	4.0
Operational history	1.0	3.5	4.0	4.0	3.5	4.0
Score (20 poss.)	2.0	7.0	8.0	8.0	7.0	8.0
Conservation						
Material recovery	2.5	1.0	2.5	3.0	4.0	2.0
Power usage (20 poss.)	4.0	3.0	2.0	3.5	3.5	4.0
Fuel usage	1.5	2.0	3.5	3.0	2.5	2.5
Score	8.0	6.0	8.5	9.5	10.0	8.5
Total Score	28.5	34.0	30.50	40.50	34.5	42.5

*Description of Alternatives:

1. Conventional incinerator
2. Fluff RDF (suspension)
3. Reilly slag-forming incinerator
4. Densified RDF
5. Pyrolysis
6. Dust RDF (suspension)

APPENDIX E:

CRE SYSTEM SITE SELECTION

General

This appendix summarizes criteria governing selection of a site for the new CRE plant and presents the rationale supporting siting adjacent to the existing heating plant C-1432.

Basic Criteria

Basic site selection criteria are shown in Table E1.

Site Selection

The proposed location for the new CRE plant adjacent to the existing heating plant C-1432 was chosen for the following reasons:

1. The site is accessible over main roads.

2. Adequate area and screening are available.

3. Soil conditions and grades are such that sitework is minimal.

4. Existing utilities of required capacity are nearby.

5. Location near an existing major boiler plant allows use of existing water treatment facilities and main steam header for steam distribution, thus minimizing construction and facility costs.

6. The site is near the existing landfill, facilitating disposal of ash, residue, bulky incombustibles, and potential excess waste fuel.

7. Because the site is near main roads to the landfill, delivery of waste to the new CRE facility will not require rerouting of waste collection vehicles, which often is required when a waste disposal point is changed.

A general plan of the proposed site is shown in Figure E1.

Table E1

General CRE Plant Site Selection Factors

Factor	Design Criteria	Comment
Accessibility	Incinerator should be near source of waste and near roads for trucks.	
Waste storage		Wind direction and distance to other buildings affect complaints about odors.
Steam plume from scrubbers		Locate away from areas which may be affected by fallout.
Soil conditions		Affect foundations and drainage.
Grades	Employ two levels where possible to facilitate charging and ash removal without hoisting and improve drainage of storm water and sewage.	
Storage facilities	Required for waste and ash containers.	
Electric service	Required for motors, lights, and controls.	
Steam distribution		Should be nearby to reduce costs.
Plumbing service	Hot water required for washing ash containers; storm and sanitary sewers required.	
Climate		Affects type of enclosure.
Permanency		Consider possibility of incinerator portability for use at another installation.

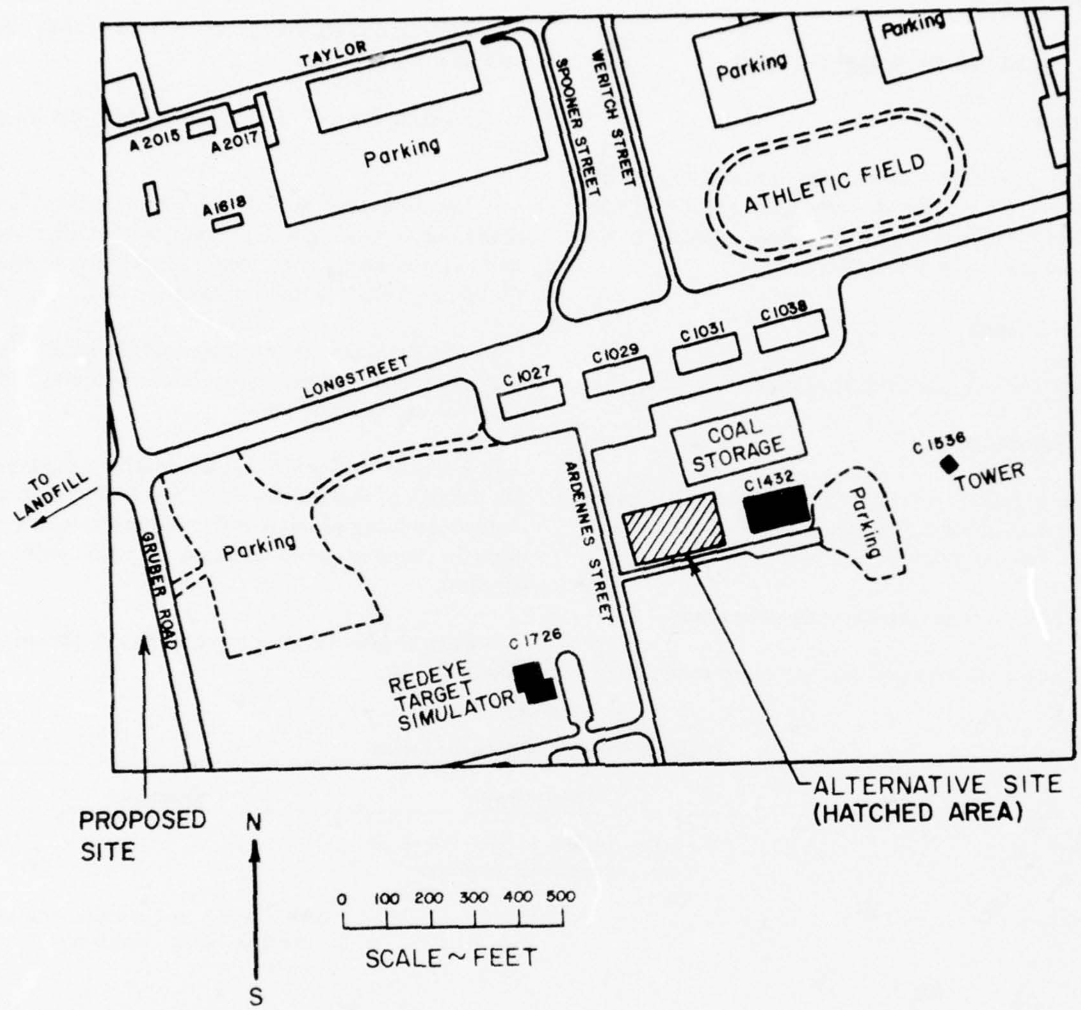


Figure E1. Ft. Bragg: proposed site for CRE facility.

APPENDIX F:

ANALYSIS OF ALTERNATIVE CRE SCENARIOS

General

This appendix summarizes the process flow and basic cost/development for the technically recommended CRE system under each of the following waste management scenarios:

1. Military alone (Ft. Bragg, Pope AFB)

2. Military-civilian (Fayetteville)

3. Military-civilian (Fayetteville, Cumberland County).

For each waste management scenario, consideration was given to production of both heating/cooling steam and electrical power at Ft. Bragg.

Guidelines

The following requirements determined in consultation with the Ft. Bragg Facilities Engineer guided development of process flows and basic costs for each technically recommended CRE system:

1. In military-civilian systems, all solid waste is taken to Ft. Bragg, which will landfill excess.

2. The military sector incurs all solid waste processing and using costs. The costs incurred by the civilian sector are limited to construction and operation of transfer station(s), if required, and possible minor increases in hauling costs due to change in solid waste disposal/delivery point.

3. Oversize bulky combustible wastes will be delivered to Ft. Bragg. About 80 percent of oversize bulky incombustible wastes generated in the civilian sector are separated from the mixed solid waste stream at civilian solid waste transfer station(s).

4. No dump fee is assessed civilian haulers, whose main responsibility is delivering mixed solid waste, with most oversize bulky incombustible and other highly undesirable wastes removed, to the CRE plant at Ft. Bragg.

5. The military sector achieves negligible reduction of required capital and annual expenditures for collecting and hauling solid waste. Collection and hauling solid waste at Ft. Bragg and Pope AFB continue according to the present system, but delivery is to the CRE plant. Use of landfill continues, but for disposal of excess solid waste and ash and residue from the CRE plant. Cost development considered the CRE plant a project separate from (but, logistically, integrated into) standing operation sanitary hauling.

Development of Design Points

Design points used in the investigation are displayed for each waste management scenario in Tables F1 and F2. Design points for civilian and military solid waste reflect a 25 percent increase over measured quantities shown in Tables A4 and A5. The design point was determined only for the purpose of hardware sizing. In cost development, credits for clean fuel displaced by producing steam from solid waste and reduction in purchased electrical power are determined from real rather than design quantities.

Federal and State stationary source emission standards applicable to incinerators and boilers are

Table F1

Ft. Bragg: Summary of Mass Design Points for CRE Scenarios

Scenario	Generation Rate (TPD_5) Real	Generation Rate (TPD_5) Design	Generation Rate (TPY) Real	Generation Rate (TPY) Design	Ash Removal Requirement (TPY)* Real	Ash Removal Requirement (TPY)* Design
Military alone	135.2	169.0	35,152	43,940	4,406	5,508
Military-Fayetteville	243.0	304.0	63,232	79,040	14,543	18,179
Military-Fayetteville-Cumberland County	465.0	581.0	120,900	151,125	29,893	37,366

*Includes 15 percent contingency.

Table F2

Ft. Bragg: Summary of Heating Value Design Points for CRE Scenarios

Scenario	Lower Heating Value (MBtu/day) Real	Lower Heating Value (MBtu/day) Design	Lower Heating Value (MBtu/yr) Real	Lower Heating Value (MBtu/yr) Design
Military alone	1914	2393	497,682	622,103
Military-Fayetteville*	2916	3645	758,160	947,700
Military-Fayetteville-Cumberland County	5434	6792	1,412,837	1,766,047

*Based on 6000 Btu/lb for combined waste stream.

Table F3

Ft. Bragg: Stationary Source Emission Standards for New Boilers and Incinerators

Source	Applicability	Particulate	Regulation Oxides of Nitrogen
Federal	Fossil fuel boilers > 250 MBtu/hr	0.1 lb/MBtu	0.7 lb/MBtu
	Incinerators > 50 TPD	0.8 gr/scf (0.16 lb/MBtu)	None
North Carolina	"Fuel burning sources"* 100 > 1000 MBtu/hr	0.25 lb/hr (0.18 lb/MBtu)	—
	"Refuse burning equipment"		
	> 1 TPH	4 lb/hr	—
	5 TPH	10 lb/hr	—
	10 TPH	13 lb/hr	—
	15 TPH	16 lb/hr	—
	20 TPH	18 lb/hr	—
	25 TPH	20 lb/hr	—
	50 TPH	27 lb/hr	—
	100 TPH	37 lb/hr	—

*Combustion apparatus for production of steam or power.

shown in Table F3. The most stringent standards must be followed.

Basic Process Flow

Individual process flows for the waste management scenarios outlined above are generally comparable. Individual differences are discussed under separate treatment of each alternative scenario. The basic process flow is shown in Figure F1.

General

The recommended facility is a multiple-purpose, self-contained installation which incorporates all equipment and devices necessary for handling and incinerating solid waste, and producing saturated steam at 160 psig nominal. The steam generated will be fed to the existing main header at the 82nd Airborne Division Heating Plant (Building C-1432). The CRE plant takes preference in the general operating sequence of supplying steam to installation users linked to C-1432. Initial materials resource recovery is limited to ferrous metals. The basic process steps are (1) preparation of solid waste into RDF, (2) RDF storage and feed, (3) RDF incineration, (4) heat recovery, and (5) air pollution control.

RDF Preparation

Vehicles delivering solid waste to the CRE plant are weighed on a standard platform truck scale at

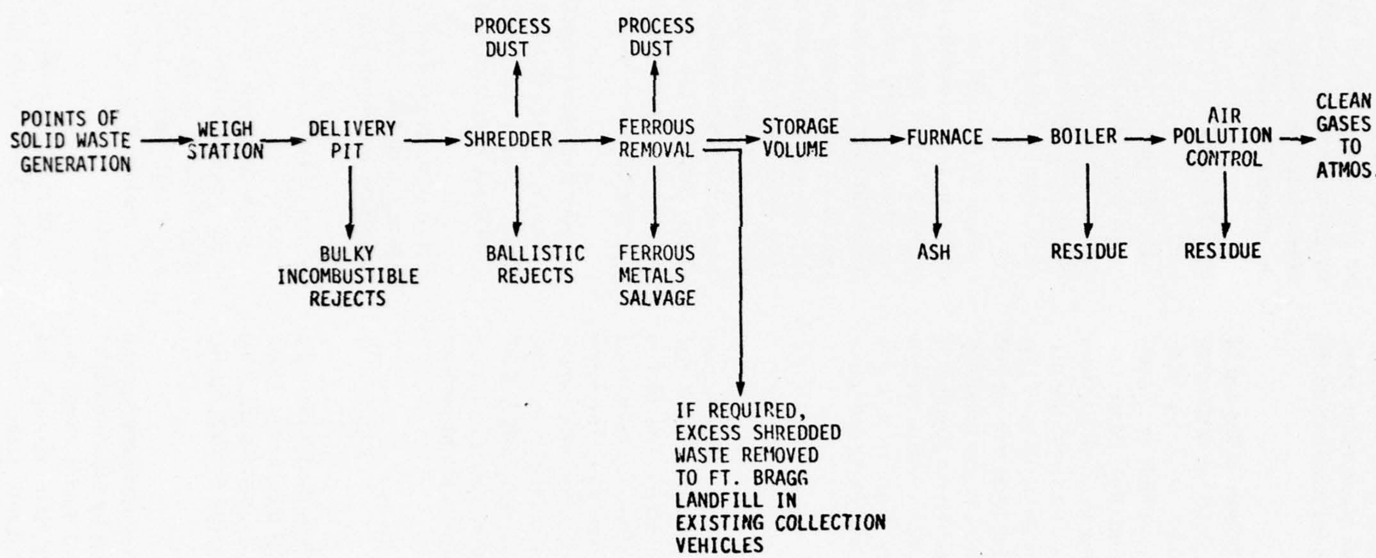


Figure F1. Ft. Bragg: basic process flow for waste management/CRE scenarios.

the entrance to the building. Solid waste is deposited by collection vehicles onto a tipping floor inside the building. A front-end loader moves the solid waste to the shredder feed conveyor, which is an adjustable speed, heavy duty inclined steel piano hinge type, with flights designed specifically for handling mixed solid waste.

Solid waste is conveyed to a hopper at the top of the shredder, where it drops through the feed opening. The recommended shredder is a top-feed, bottom extraction, heavy duty, reversible drive hammermill with replaceable hammertips. Most material is broken to minus 3 inches (with all particles less than 12 inches) and drops directly to the discharge conveyor. Ballistic rejects (material not capable of passing through the shredder) are ejected through the ballistics chute for separate handling. RDF is conveyed through a load-leveling guillotine to a pulley magnet for removal of recyclable ferrous materials. RDF is then conveyed up an inclined, covered troughed belt conveyor and deposited into a live-bottom storage bin.

RDF Storage and Feed

The storage bin is of reinforced concrete integrated into building structure and is of sufficient size to hold 1½ days of processed RDF. The fuel is moved along the bottom of the bin to an enclosed screw conveyor along the bin frontwall. The screw conveyor discharges onto a belt conveyor which moves the RDF to the feed hopper of the incinerator. The feed hopper is of sufficient capacity to hold RDF quantities for 1 hour of incinerator operation (i.e., a head of RDF is constantly present in the incinerator feed hopper).

Incineration

RDF is periodically injected into the furnace by a hydraulically powered ram feeder mechanism. Upon injection, RDF falls upon the double reciprocating grate which continually mixes the charge during combustion.

RDF undergoes largely self-sustained combustion after initial ignition on cold start by conventional oil burner. Three flights of inclined double reciprocating grates move the burning RDF through the furnace. Adjustment of ram feed rate, stoking rate, and underfire and overfire air flow rates insures maximum burnout of the RDF by the time it has moved the length of the grate. Ash drops into a quench tank below the end of the furnace.

Hot off-gases and entrained combustibles pass to an afterburning section where heat is added to the stream and remaining combustibles are burned. The afterburning section also sustains boiler operation in the absence of an RDF load.

Heat Recovery

Hot off-gases pass from the afterburning section to the boiler. The recommended watertube heat exchanger is a staggered "D" type equipped with sootblowers and ash hoppers beneath gas passes. Saturated steam at 160 psig nominal is produced.

Gases pass from the boiler at 600°F and are cooled to the maximum temperature allowable for the air pollution control apparatus. Although addition of economizers would increase the overall wet boiler efficiency, experience on refuse-fired boiler systems shows that economizers are subject to corrosion, flyash erosion, and clogging problems. Similarly, evaporative spray cooling is not recommended because it is an energy-intensive and inefficient approach when temperatures must be cooled by only about 200°F. The recommended approach is ambient air dilution cooling using automatic temperature-controlled louvre dampers.

Boiler feedwater is supplied from existing facilities at nearby C-1432 (82nd Airborne Division Heating Plant). Steam and water handling facilities at C-1432 are integrated into the CRE system.

The boiler is provided with a safety heat dissipation fan/tube heat exchanger capable of dissipating heat from steam generated in excess of demand.

Generation of Electrical Power

Under Scenarios 1B, 2B, and 3B, the CRE facility is equipped to produce electrical power. Generation is anticipated to take place during daytime for 5 spring and summer months. At other times, steam for heating and cooling is the principal plant product.

The electrical power generation scenarios have a process flow generally similar to that for those dealing with producing steam for heating and cooling. A separate, clean fuel-fired steam superheater is pro-

vided. Superheated, high pressure steam is used to run a noncondensing steam turbine generator. Under the optimal design concept, steam outlet conditions from the generator are compatible for further use for heating and cooling through the C-1432 distribution system. A portion of the hot combustion products from the superheater is routed to the waste incinerator for use as preheated combustion air, thereby reducing incinerator auxiliary fuel requirements.

The advantages of providing a separate superheater include plant flexibility and reduced superheater material wastage rates due to its removal from exposure to dirty and chemically aggressive incinerator furnace off-gases. A major disadvantage is generally lower plant efficiency, but this is somewhat counterbalanced by increased reliability over the system's economic life.

Air Pollution Control

Gases passing from the boiler to the air pollution control apparatus are cooled by ambient air dilution. An automatic water quench system is included before the air pollution control apparatus to reduce gas temperatures to a level which will not damage the apparatus and induced draft fan. Particulate material is removed from the off-gas stream by a multiclone dust collector designed to remove more than 90 percent of all particulates greater than 10 microns. Due to the afterburning stage between furnace and boiler, emission of particulate material and complex organic compounds is expected to be relatively minor and well within existing legal levels. Fly ash from the bottom of the cyclone is collected in a container for disposal.

Controls

All operational controls are located at the control room where operators have direct visual contact with the receiving area shredder, storage bin, and charging hoppers. Visual monitoring of other critical areas can be by video camera.

Building

The recommended building is a steel-framed, insulated metal-clad structure housing the complete facility. A free span roof is provided over the tipping area. A column-supported roof houses all process equipment.

Excesses

At certain times under some waste management scenarios, waste in excess of heating/cooling steam requirements is available. The analysis presumed that during these periods, the CRE system is operated at minimal load (about 60 percent) to reduce excess steam, which is circulated through a heat sink. Electrical power production was assumed to take place 5 months of the year (May through September) for the hours 1000 to 2200 (12 hr/day). Excess waste delivered to the new CRE plant is not burned, but is processed through the shredding and metals removal stages. Under this operation, metals recovery continues. The bulk-reduced solid waste is then moved to the Ft. Bragg landfill for disposal. The recommended vehicle is a 60-cu yd truck with a hydraulic ejector. This type of disposal operation resembles the "shred-and-spread" system used in numerous municipalities. Shredded waste, deposited at the Ft. Bragg landfill, is compacted and covered at the end of each operating day.

CRE Scenario 1A

General

CRE Scenario 1A pertains only to the military solid waste stream and production of steam for heating and cooling. The process flow compares to the basic system process flow described above. Delivered solid waste passes through a shredder and magnetics removal system to temporary storage. RDF is removed from the live-bottom storage bin by screw conveyor and dumped into the incinerator feed hopper. RDF is hydraulically ram-fed into the incinerator. The stoker is a three-flight double reciprocating grate. Ash falls to a quench from which it is conveyed to containers for disposal. Gases pass from the furnace at 1800°F through a watertube boiler. After the boiler, dilution air is added to reduce gas temperature from 650°F to 490°F. Cooled gases pass through a multiclone for particulate removal and are vented to the atmosphere through a stack equipped with spark arrestor.

The design steaming capacity is about 60,800 lb/hr. The expected average steam production rate is 45,646 lb/hr. Operation is 24 hr/day, 5 days/week, with weekends available for extended operation and routine maintenance. All steam produced at the new CRE plant is run to the existing main header at C-1432 for distribution. All steam produced at the

new CRE plant is used, with production supplemented by boilers at C-1432.

Fuel Savings

As shown in Table F4, annual fuel savings total approximately 2 million gal, equivalent to $736,834/yr.

Table F4

Ft. Bragg: Computation of Fuel Oil Savings for Scenario 1A CRE System

	Average Hourly Steam Demand for C-1432 (Table C4)*	RDF-Derived Steam Excess	RDF-Derived Steam Deficit**	RDF Steam Use Factor
January	100,876	—	55,230	100%
February	109,595	—	63,949	100%
March	98,397	—	52,751	100%
April	65,974	—	20,328	100%
May	46,781	—	1,135	100%
June	49,445	—	3,799	100%
July	51,142	—	5,496	100%
August	58,134	—	12,488	100%
September	49,351	—	3,705	100%
October	52,282	—	6,636	100%
November	82,581	—	36,935	100%
December	96,583	—	50,937	100%
				Avg. = 100%

Real steam production = 45,646 lb/hr from RDF (no excess)

Fuel oil equivalent (savings) (usage factor = 100%)

Steam	45,646 lb/hr
Btu	$45,646 \times 1018 = 46.47 \times 10^6$
Efficiency	$46.47 \times 10^6/0.85 = 54.67 \times 10^6$ Btu/hr
Yearly	$54.67 \times 10^6 \times 24 \times 5 \times 52 = 341,127 \times 10^6$
Availability	$341,127 \times 10^6 \times 0.90 = 307,014 \times 10^6$ Btu/yr†
Fuel oil eq.	$307,014 \times 10^6/150,000 = 2,046,762$ gal/yr
Fuel oil value	2,046,762 gal/yr @ $0.36/gal = $736,834/yr

*Calculated.

**C-1432 heating plant continues to operate but at reduced level.

†Availability of 0.90 due to available weekend maintenance periods.

Capital Cost Requirement

The investment requirement for the Scenario 1A CRE facility is $3,799,000, as shown in the detailed equipment breakdown in Table F7. Costs are current (FY76) dollars. Project costs based to FY81 are given in Appendix G.

Annual Cost Requirement

The annual cost requirement for the scenario 1A CRE facility is summarized in Table F8. Debits (the annual cost of operating and maintaining the new CRE facility) total $417,000/yr. Credits are taken for (1) avoided costs of operating and maintaining plant C-1432, (2) fuel oil saved by using RDF to produce steam, and (3) use of operation and maintenance (O&M) items in the new CRE plant which are already budgeted for the existing plant C-1432 (such as boiler feedwater). Credits total $842,900, and do not include indeterminate reductions in the Ft. Bragg landfill operation. The total annual requirement (debits less credits) is an effective savings of $425,900/yr. All debits and credits are current (FY76) dollars.

Civilian Requirements

There are no civilian requirements.

Scenario 1B

General

CRE Scenario 1B pertains only to the military solid waste stream and production of (1) saturated medium-pressure steam for heating and cooling and (2) superheated steam for production of electrical power. The general process flow is similar to that given for Scenario 1A. This scenario adds a separately fired steam superheater and a noncondensing steam turbine generator for production of electrical power during 5 spring and summer months for 12 hr/day, 5 days/week.

Energy Savings

Fuel oil credits achieved are essentially the same as under the Scenario 1A CRE system, 2,046,762 gal/yr ($786,834/yr). Electrical power credits are twofold. The annual electrical energy production rate operating 21.5 days/month, 12 hr/day for 5 months is 21.5 x 12 x 5 x 4406 kW or 5,683,740 kWh. At $0.0137/kWh this represents a savings of $77,867/yr. In addition, five monthly peaks will be diminished, resulting in a savings of 4406 x 5 x 3.75 = $82,613/yr. The total electrical energy savings is $160,480/yr.

Capital Cost Requirement

The investment requirement for the Scenario 1B CRE facility is $6,316,000, as shown in Table F7. Costs are current (FY76) dollars. Project costs based to FY81 are given in Appendix G.

Annual Cost Requirement

Table F8 summarizes annual debits and credits for the Scenario 1B CRE system. Annual operating debits total $564,800, while credits (avoided costs) total $1,003,400. The annual cost is hence an effective savings of $438,600 (FY76 dollars).

Civilian Requirements

There are no civilian requirements.

CRE Scenario 2A

General

CRE Scenario 2A pertains to the combined military-civilian (Fayetteville) waste stream, excluding solid waste generated in Cumberland County outside Fayetteville. The process flow compares to the basic systems process flow described above. Delivered solid waste passes through a shredder and magnetics separator to temporary storage. RDF is removed from the storage bin by screw conveyor and dumped into the incinerator feed hopper. RDF is hydraulically ram-fed into the incinerator. The stoker is a three-flight double reciprocating grate. Ash falls to a quench from which it is conveyed to containers for removal. Gases pass from the furnace at 1800°F through a watertube boiler. After the boiler, dilution air is added to reduce gas temperature from 650°F to 490°F. Cooled gases pass through a multiclone for removal of particulate matter and are vented to the atmosphere through a stack equipped with spark arrestor.

The design steaming capacity is 72,167 lb/hr. The expected average steam production rate is 54,125 lb/hr. Operation is 24 hr/day, 7 days/week with scheduled maintenance downtime during the year. Excess steam is producible 5 months of the year. Excesses can be eliminated by reducing boiler load and landfilling excess RDF. Steam produced at the new CRE plant is run to the existing header at C-1432 for distribution. Winter season steam requirements are met by increasing CRE plant boiler load and operating units at C-1432.

Fuel Savings

As shown in Table F5, annual fuel savings total 3.1 million gal, equivalent to $1,116,674/yr.

Table F5

Ft. Bragg: Computation of Fuel Oil Savings for Scenario 2A CRE System

	Average Hourly Steam Demand for C-1432 (Table C4)*	RDF-Derived Steam Excess	RDF-Derived Steam Deficit**	RDF Steam Use Factor
January	100,876	—	46,751	100%
February	109,595	—	55,470	100%
March	98,397	—	44,272	100%
April	65,974	—	11,849	100%
May	46,781	7,344	—	86.43%
June	49,445	4,680	—	91.35%
July	51,142	2,983	—	94.49%
August	58,134	—	4,009	100%
September	49,351	4,774	—	91.18%
October	52,282	1,843	—	96.59%
November	82,581		28,396	100%
December	96,583		42,458	100%
				Avg. = 96.67

Real steam production = 54,125 lb/hr from RDF

Fuel oil equivalent (savings)

Steam	54,125 lb/hr
Btu	$54,125 \times 1018 = 55.10 \times 10^6$ Btu/hr
Efficiency	$55.10 \times 10^6 / 0.85 = 64.82 \times 10^6$ Btu/hr
Yearly	$64.82 \times 10^6 \times 24 \times 7 \times 52 = 566,291 \times 10^6$ Btu/yr
Availability	$566,291 \times 10^6 \times 0.85 = 481,347 \times 10^6$ Btu/yr†
Usage factor	$481,347 \times 10^6$ Btu/yr $\times$ 0.9667 = $465,318 \times 10^6$ Btu/yr
Fuel oil eq.	$465,318 \times 10^6 / 150,000 = 3,102,121$ gal/yr
Fuel oil value	3,102,121 gal/yr @ $0.36/gal = $1,116,674/yr

*Calculated

**C-1432 heating plant has reduced operation with shutdown for 5 months.

†Availability of 0.85 due to scheduled maintenance requirement and contingency.

Capital Cost Requirement

The investment requirement for the Scenario 2A CRE facility is $4,886,600, as shown in the detailed equipment breakdown in Table F7. Costs are current (FY76) dollars.

Annual Cost Requirement

The annual cost requirement for the Scenario 2A CRE facility is summarized in Table F8. Debits (the annual cost of operating and maintaining the new CRE facility) total $634,400/yr. Credits are taken for (1) avoided costs of operating and maintaining plant C-1432, (2) fuel saved by using RDF to produce steam, and (3) use of O&M items in the new CRE plant which are already budgeted for the exist-

ing plant C-1432. Credits total $1,265,300, and do not include indeterminate reductions in the Ft. Bragg landfill operation. The total annual requirement (debits less credits) is an effective savings of $630,900/yr. All debits and credits are current (FY76) dollars. Cost analyses based to FY81 are provided in Appendix G.

Civilian Requirements

The civilian sector must deliver solid waste to the new CRE plant at Ft. Bragg on a regular schedule. Transfer stations, if required, will be built and operated at civilian expense in the civilian sector. Waste delivered to Ft. Bragg should be devoid of bulky incombustibles (such as large appliances) and hazardous and particularly obnoxious materials.

CRE Scenario 2B

General

CRE Scenario 2B pertains to the combined military-civilian (Fayetteville) waste stream. Medium-pressure saturated steam for heating and cooling is the principal plant product. During 5 months of the year, superheated steam for power generation is produced. The general process flow resembles that of Scenario 2A. This scenario adds a separate superheater and steam turbine generator.

Energy Savings

Fuel oil credits achieved are essentially the same as under the Scenario 2A CRE system, 3,102,121 gal/yr ($1,116,674/yr). Electrical power credits are twofold. The annual electrical energy production rate operating 21.5 days/month, 12 hr/day, for 5 months is 21.5 x 12 x 5 x 5224 = 6,738,960 kWh, which at $0.0137/kWh, is a savings of $92,324/yr. In addition, five monthly peaks will be diminished, resulting in a savings of 5224 x 5 x 3.75 = $97,950/yr.

Capital Cost Requirement

The investment requirement for the Scenario 2B CRE facility is $7,862,200, as shown in Table F7. Costs are current (FY76) dollars. Project costs based to FY81 are given in Appendix G.

Annual Cost Requirement

Table F8 summarizes annual debits and credits for the Scenario 2B CRE system. Annual operating debits total $857,100, while credits (avoided costs) total $1,455,600. The annual cost is hence an effective savings of $598,500 (FY76 dollars).

Civilian Requirements

The civilian sector must deliver solid waste to the new CRE plant at Ft. Bragg on a regular schedule. Transfer stations, if required, will be built and operated at civilian expense in the civilian sector. Waste delivered to Ft. Bragg should be devoid of bulky incombustibles (such as large appliances) and hazardous and particularly obnoxious materials.

CRE Scenario 3A

General

CRE Scenario 3A pertains to the combined military-civilian (Fayetteville and Cumberland County) waste stream. The process flow compares to the basic systems process flow described earlier. Delivered solid waste passes through a shredder and magnetics separator to temporary storage. RDF is removed from the storage bin by screw conveyor and dumped into the incinerator feed hopper. RDF is hydraulically ram-fed into the incinerator. The stoker is a three-flight double reciprocating grate. Ash falls to a quench from which it is conveyed to containers for removal. Gases pass from the furnace at 1800°F through a watertube boiler. After the boiler, dilution air is added to reduce gas temperature from 650°F to 490°F. Cooled gases pass through a multiclone for removal of particulate matter and are vented to the atmosphere through a stack equipped with spark arrestor.

The design steaming capacity is 126,415 lb/hr. The expected average steam production rate is 94,811 lb/hr. Operation is 24 hr/day, 7 days/week, with scheduled maintenance downtime during the year. Excess steam is producible 8 continuous months of the year (April through November). Excess can be minimized by operating at reduced boiler load and landfilling excess RDF. Steam produced at the new CRE plant is run to the existing header at C-1432 for distribution. Winter season steam requirements are met by increasing CRE plant boiler load and operating units at C-1432.

Fuel Savings

As shown in Table F6, annual fuel savings total 4.1 million gal, equivalent to $1,479,271/yr.

Table F6

Ft. Bragg: Computation of Fuel Oil Savings for Scenario 3A CRE System

	Average Hourly Steam Production for C-1432 (Table C4)* (lb/hr)	RDF-Derived Steam Excess (lb/hr)	RDF-Derived Steam Deficit** (lb/hr)	RDF Steam Use Factor
January	100,876	—	6,065	100%
February	109,595	—	14,784	100%
March	98,377	—	3,566	100%
April	65,974	28,837	—	69.58%
May	46,781	51,630	—	45.54%
June	49,445	45,366	—	52.15%
July	51,142	43,669	—	54.26%
August	58,134	36,677	—	61.32%
September	49,351	45,460	—	52.05%
October	52,282	42,529	—	55.14%
November	82,581	12,230	—	87.10%
December	96,583		1,772	100%
				Avg. = 73.10%

Real steam production = 94,811 lb/hr from RDF

Fuel oil equivalent (savings)

Steam	94,811 lb/hr
Btu	$94{,}811 \times 1018 = 96.52 \times 10^6$ Btu/hr
Efficiency	$96.52 \times 10^6/0.85 = 113.55 \times 10^6$ Btu/hr
Yearly	$113.55 \times 10^6 \times 24 \times 7 \times 52 = 991{,}974 \times 10^6$ Btu/yr
Availability	$991{,}974 \times 10^6 \times 0.85 = 843{,}178 \times 10^6$ Btu/yr†
Usage factor	$843{,}178 \times 10^6 \times 0.7310 = 616{,}363 \times 10^6$ Btu/yr
Fuel oil eq.	$616{,}363 \times 10^6/150{,}000 = 4{,}109{,}087$ gal/yr
Fuel oil value	4,109,087 gal/yr @ $0.36/gal = $1,479,271/yr

*Calculated.

**C-1432 heating plant has reduced operation with shutdown for 8 months.

†Availability of 0.85 due to scheduled maintenance requirement and contingency.

Capital Cost Requirement

The investment requirement for the Scenario 3A CRE facility is $6,123,400 as shown in the detailed equipment breakdown in Table F7. Costs are current (FY76) dollars. A cost analysis based to FY81 dollars is given in Appendix G.

Annual Cost Requirement

The annual cost requirement for the Scenario 3A CRE system is summarized in Table F8. Debits (the annual cost of operating and maintaining the new CRE facility) total $1,019,000. Credits are taken for (1) avoided costs of operating and maintaining plant C-1432, (2) fuel saved by using RDF to produce steam, and (3) use of O&M items in the new CRE plant which are already budgeted for the existing plant C-1432. Credits total $1,717,400, and do not include indeterminate reductions in the Ft. Bragg landfill operation. The total annual requirement (debits less credits) is an effective savings of $698,400/yr. All debits and credits are current (FY76) dollars. An economic analysis based on FY81 dollars is given in Appendix G.

Civilian Requirements

The civilian sector must deliver solid waste to the new CRE plant at Ft. Bragg on a regular schedule. Transfer stations, if required, will be built and operated at civilian expense in the civilian sector. Waste delivered to Ft. Bragg should be devoid of bulky incombustibles (such as large appliances) and hazardous and particularly obnoxious materials.

CRE Scenario 3B

General

CRE Scenario 3B pertains to the combined military-civilian (Fayetteville and Cumberland County) waste stream. The principal plant product is medium-pressure steam for heating and cooling. During 5 months of the year, superheated steam for power generation is produced. The general process flow resembles that of Scenario 3A. This scenario adds a separate superheater and a steam turbine generator.

Energy Savings

Fuel oil credits achieved are essentially the same as under the Scenario 3A CRE system, 4,109,087 gal/yr ($1,479,271/yr). Electrical power credits are twofold. The annual electrical energy production rate operating 21.5 days/month, 12 hr/day, for 5 months is 21.5 x 12 x 5 x 9152 = 11,806,080 kWh, which, at $0.0137/kWh, is a savings of $161,743/yr. In addition, five monthly peaks will be diminished, resulting in a savings of 9152 x 5 x 3.75 = $171,600/yr.

Capital Cost Requirement

The investment requirement for the Scenario 3B CRE facility is $9,611,100, as shown in Table F7. Costs are current (FY76) dollars. Project costs based to FY81 are given in Appendix G.

Annual Cost Requirement

Table F8 summarizes annual debits and credits for the Scenario 3B CRE system. Annual operating

Table F7

Economic Development of CRE Scenarios: Capital Investment Requirements

	Energy-Recovery Scenario 1A	1B	2A	2B	3A	3B
Capital Investment Requirement						
1. RDF Preparation						
Platform scale weigh station	18.6		18.6		18.6	
Front-end loader	20.0		20.0		30.0	
Elevating feed conveyor	15.0		19.6		29.0	
Solid waste shredder	216.0		315.5		387.5	
Shredder discharge feeder	41.0		54.0		61.0	
Ferrous removal system	47.0		63.8		70.0	
Elevated conveyor	50.0		60.0		69.0	
Miscellaneous electrical	60.0		65.0		68.0	
Total	467.6	467.6	616.5	616.5	733.1	723.1
2. RDF Storage						
Live-bottom hopper	102.5		138.7		185.0	
Screw conveyor	11.7		16.4		19.8	
Miscellaneous electrical	21.5		22.8		24.0	
Total	135.7	135.7	177.9	177.9	228.8	228.8
3. Incinerator/Heat Recovery						
Feed hopper	9.2		16.8		21.5	
Hydraulic ram feeder	49.0		57.5		73.2	
Three-flight double reciprocating grate stoker	95.6		176.1		226.6	
Fans and blowers	78.0		112.5		156.4	
Emergency quench package	5.0		5.8		6.1	
Multiclone particulate collection system	45.3		51.0		87.0	
Drag flight residue conveyor	71.0		84.5		98.5	
Monolithic refractory furnace	705.0		992.4		1,350.0	
Oil/gas afterburner	7.1		8.3		10.4	
Stack, spark arrestor	57.0		63.4		85.0	
Boiler (watertube staggered "D" type)	120.0		180.0		215.0	
Heat sink package	14.0		17.5		25.4	
Steam line to C-1432	18.0		19.5		26.5	
Feedwater line from C-1432, tank	13.0		18.2		24.9	
Instrumentation and controls	61.5		65.5		66.9	
Miscellaneous mechanical equipment (piping, ductwork)	81.6	119.8	94.7	135.0	102.5	146.9
Miscellaneous electrical	79.5		88.3		100.0	
Total	1,509.8	1,548.0	2,052.0	2,092.3	2,675.9	2,720.3
4. Electrical Power Generation						
Steam superheater package	—	247.0	—	275.0	—	325.0
Steam turbine, generator	—	1,640.0	—	1,965.0	—	2,246.0
Miscellaneous mechanical	—	19.4	—	20.0	—	29.0
Miscellaneous electrical	—	18.7	—	20.0	—	31.2
Total	—	1,925.1	—	2,280.0	—	2,631.2
5. Fuel Supply						
Fuel oil line from tank at C-1432, tank	10.3	24.8	12.4	31.5	16.5	39.0
Natural gas line	4.1	5.9	5.6	6.2	6.2	13.0
Total	14.4	30.7	18.0	37.7	22.7	52.0

Table F7 (cont'd.)

	Energy-Recovery Scenario					
	1A	**1B**	**2A**	**2B**	**3A**	**3B**
6. Building						
Slab on grade	104.9		125.4		190.0	
Slab above grade	61.2		73.1		85.6	
Walls	144.0		165.6		195.0	
Machinery base	9.2	10.4	12.0	12.9	18.5	19.5
Masonry	6.5		7.1		9.2	
Preengineered steel-clad building	335.2		382.5		415.0	
Internal	8.5	9.7	10.0	12.4	16.5	18.0
HVAC	8.1		9.6		12.5	
Stairs, ladders, railing	39.5		44.5		57.8	
Miscellaneous mechanical	21.6	32.4	22.5	36.1	23.9	57.5
Miscellaneous electrical	49.8	55.9	51.0	57.0	54.0	92.6
Expense items	25.0		25.0		25.0	
Total	813.5	832.8	928.3	951.2	1,103.0	1,177.7
7. Sitework						
Earthwork	41.2		50.0		57.9	
Fence and gates	18.0		19.5		20.0	
Piping	7.1		8.0		9.4	
Paving	3.6		4.4		5.9	
Grass and landscape	5.9		5.9		5.9	
Total	75.8	75.8	87.8	87.8	99.1	99.1
Total Equipment (items 1-5)	2,127.5	4,107.0	2,864.4	5,204.4	3,660.5	6,355.4
Total Facility (items 6, 7)	889.3	908.6	1,016.1	1,039.0	1,202.1	1,276.8
Total Equipment and Facility	3,016.8	5,015.6	3,880.5	6,243.4	4,862.6	7,632.2
Accumulate 8% Contingency (incl. startup)	3,258.1	5,416.8	4,190.9	6,742.9	5,251.6	8,242.8
Accumulate 10% Contractor Profit	3,584.0	5,958.5	4,610.0	7,417.2	5,776.8	9,067.1
Accumulate 6% A/E Design	3,799.0	6,316.0	4,886.6	7,862.2	6,123.4	9,611.1
Project Capital (FY76 dollars)	3,799.0	6,316.0	4,886.6	7,862.2	6,123.4	9,611.1

Table F8

Economic Development of CRE Scenarios: First-Year Recurring Costs

	Energy Recovery Scenario					
	1A	**1B**	**2A**	**2B**	**3A**	**3B**
Plant Operating and Maintenance Costs (Debits)						
Labor crew (costs include overhead, benefits, etc.)						
RDF operator (front end loader, shredder; $8.50/hr)	53.1		74.3		148.6	
Furnace-boiler operator ($8.50/hr)	53.1		74.3		74.3	
General maintenance ($6.75/hr)	42.1		59.0		59.0	
General maintenance ($6.75/hr)	14.0		19.7		59.0	
Helper ($5.90/hr)	12.1		17.2		17.2	
Supervisory/administrative ($12.50/hr)	13.0		13.0		13.0	
Total	187.4	187.4	257.5	257.5	371.1	371.1
Electrical power ($0.0137/kWh)						
Process equipment	24.1	31.2	43.3	56.1	82.8	107.3
General plant	6.0		8.4		20.6	
Total	30.1	37.2	51.7	64.5	103.4	127.9

Table F8 (cont'd.)

	Energy Recovery Scenario					
	1A	1B	2A	2B	3A	3B
Vehicle fuel ($0.65/gal)						
Front-end loaders (2 gal/ton)	57.1		102.8		196.4	
Total	57.1	57.1	102.8	102.8	196.4	196.4
Combustor fuel ($0.36/gal)						
Incinerator	12.2		16.0		41.3	
Superheater	—	70.7	—	127.2		243.0
Total	12.2	82.9	16.0	143.2	41.3	284.3
Water ($0.50/kgal)						
Steam generators	*	*	*	*	*	*
General plant	5.6		7.9		8.1	
Total	5.6	5.6	7.9	7.9	8.1	8.1
Maintenance and repairs (3½% unadjusted capital)						
Plant	105.6	175.6	135.8	218.5	169.8	267.1
Total	105.6	175.6	135.8	218.5	169.8	267.1
Ash and residue disposal (Ft. Bragg landfill; $3.45/ton)						
Plant	19.0		62.7		128.9	
Total	19.0	19.0	62.7	62.7	128.9	128.9
Total Plant Operating Debits	417.0	564.8	634.4	857.1	1,019.0	1,383.8
Credits (Avoided or Offset Costs)						
Labor						
Man-years available from C-1432 ($8.50/hr)	35.4		52.5		88.4	
Man-years available from landfill ($6.75/hr)	14.0					
Total	49.4	49.4	66.5	66.5	102.4	102.4
Electrical power ($0.0137/kWh)						
Reduced purchased base load and peak charges through production	—	160.5		190.3		333.4
Reduced operation of C-1432	23.1		27.4		40.0	
Total	23.1	183.6	27.4	217.7	40.0	373.4
Water ($0.50/kgal)						
Boiler feedwater (all in existing C-1432 budget)	*	*	*	*	*	*
85% general plant (in existing C-1432 budget)	1.2		1.6			
Total	1.2	1.2	1.6	1.6	2.7	2.7
Maintenance and repairs						
Portion of C-1432 budget via slowdown	15.7		22.7		35.0	
Total	15.7	15.7	22.7	22.7	35.0	35.0
Recovered ferrous metals ($30.00/ton)						
Plant	16.7		30.4		58.0	
Total	16.7	16.7	30.4	30.4	58.0	58.0
Fuel oil ($0.36/gal)						
Use of waste-derived steam	736.8		1,116.7		1,479.3	
Total	736.8	736.8	1,116.7	1,116.7	1,479.3	1,479.3
Total Plant Operating Credits	842.9	1,003.4	1,265.3	1,455.6	1,717.4	2,050.8
Plant Annual Economy: Debits Less Credits (FY76 Dollars) (negative sign is effective savings)	−425.9	−438.6	−630.9	−598.5	−698.4	−667.0

*Feedwater for steam generators at C-1432 already budgeted. Full credit taken cancels out debit.

debits total $1,383,800, while credits (avoided costs) total $2,050,800. The annual cost is hence an effective savings of $667,000 (FY76 dollars).

Civilian Requirements

The civilian sector must deliver solid waste to the new CRE plant at Ft. Bragg on a regular schedule. Transfer stations, if required, will be built and operated at civilian expense in the civilian sector. Waste delivered to Ft. Bragg should be devoid of bulky incombustibles (such as large appliances) and hazardous and particularly obnoxious materials.

APPENDIX G:

COMPARATIVE COST ANALYSIS OF ALTERNATIVE CRE SCENARIOS

General

The general method of economic analysis follows guidance set forth in AR 11-28.[12] The present value (PV) method is used to calculate investment, annual, and total costs of a project over its economic life in terms of dollars at the base construction year. For annually recurring costs, the method considers inflation rates associated with individual O&M items and a 10 percent discount rate. The method also treats cost escalations between the year in which the cost estimate is made (current dollars) and the project year (base year).

In the analysis made in this investigation, capital and annual costs were derived in terms of current (FY76) dollars. These costs are shown in Tables F7 and F8. It was assumed that the project year would be FY81. Capital and annual costs were escalated (inflated) for the years FY77, FY78, FY79, and FY80 to express them in terms of FY81 dollars. It was then assumed that the facility would have an economic life of 25 years from the base year, FY81. Accordingly, the annually recurring costs were expressed in terms of their present value for the time period extending through FY2005. A different inflation rate is associated with each recurring cost element; thus their relative values change through time. The escalation rates from FY76 through FY80, and the 25-year inflation factors were obtained from Navy guidance for life-cycle (present value) economic analysis.[13]

Derivation of Present Value Multiplier

To facilitate the present value analysis, a multiplier was derived. This factor is multiplied times the unit cost and number of units of an O&M item required annually in an alternative system to determine its present value over an economic life (n) of 25 years with a discount rate (I) of 10 percent and a given inflation rate (i). The PV multiplier M is:

$$M = \frac{(1+i)[(1+I)^n - (1+i)^n]}{(1+I)^n\,(I-i)} \qquad \text{[Eq G1]}$$

The following example illustrates the derivation of the PV multiplier M. Assume that a special incinerator requires an investment of $750,000 and in its first year of operation consumes 250,000 gal of fuel oil. The cost of fuel oil is $0.36/gal, and it inflates at a rate of 12 percent/yr. The economic life of the system is assumed to be 5 years. In tabulating costs, the compound-amount factor $(I + i)^n$ for the year (first-of-year payment) is used. Table G1 tabulates the costs. The PV factor $1/(1 + I)$ is used to determine the present value of the costs. Table G2 tabulates these costs. In this example, the present value of the fuel oil consumed over 5 years is $475,148, while the first-year fuel cost is $90,000. The calculations are summarized as follows:

$$PV = \$90{,}000\left[\frac{1.12}{1.10} + \frac{(1.12)^2}{(1.10)^2} + \frac{(1.12)^3}{(1.10)^3} + \frac{(1.12)^4}{(1.10)^4} + \frac{(1.12)^5}{(1.10)^5}\right] \qquad \text{[Eq G2]}$$

where PV is the present value amount.

Table G1

Example Cost Tabulation Using Compound Amount Factor

Year		Cost ($)
0		(750,000)
1	$90{,}000\,(1.12)^1$	100,800
2	$90{,}000\,(1.12)^2$	112,896
3	$90{,}000\,(1.12)^3$	126,444
4	$90{,}000\,(1.12)^4$	141,617
5	$90{,}000\,(1.12)^5$	158,611

Table G2

Example Cost Tabulation Using PV Factor

Year		PV of Costs in Table G1
0		(750,000)
1	$100{,}800/(1.10)^1$	91,636
2	$112{,}896/(1.10)^2$	93,302
3	$126{,}444/(1.10)^3$	94,999
4	$141{,}617/(1.10)^4$	96,726
5	$158{,}611/(1.10)^5$	98,485
		475,148

[12] *Economic Analysis and Program Evaluation for Resource Management*, AR 11-28 (Department of the Army [HQDA DACA-CAF], December 1975).

[13] *Economic Analysis Handbook*, NAVFAC Document P-442 (Department of the Navy, 1975) and *Energy Escalation Rates for Short Term Costing and Life Cycle Costing*, NAVFAC Code 1023B (Department of the Navy, 23 August 1976). See also S. Hathaway and J. Woodyard, *Technical Evaluation Study: Energy Recovery Utilization of Waste at Puget Sound Naval Shipyard, Bremerton, WA*, Technical Report E-89 (CERL, 1976).

With F as the first-year fuel cost and using the nomenclature identified above, this calculation can be generalized as follows:

$$PV = F\left[\frac{1+i}{1+I} + \left(\frac{1+i}{1+I}\right)^2 + \left(\frac{1+i}{1+I}\right)^3 + \left(\frac{1+i}{1+I}\right)^4 + \left(\frac{1+i}{1+I}\right)^n\right] \quad \text{[Eq G3]}$$

where n = 5.

The following is obtained by factoring:

$$PV = F\frac{1+i}{1+I}\left[1 + \left(\frac{1+i}{1+I}\right) + \left(\frac{1+i}{1+I}\right)^2 + \left(\frac{1+i}{1+I}\right)^3 + \left(\frac{1+i}{1+I}\right)^{n-1}\right] \quad \text{[Eq G4]}$$

Letting

$$X \equiv \frac{1+i}{1+i} \quad \text{[Eq G5]}$$

and substituting into Eq G4, Eq G6 results in

$$PV = FX\,[1 + X + X^2 + \ldots + X^{n-1}] \quad \text{[Eq G6]}$$

Eq G6 is identical to

$$PV = FX\left[\frac{1-x^n}{1-x}\right] \quad \text{[Eq G7]}$$

where the multiplier M by which to find the PV cost is self-evident:

$$M = X\left[\frac{1-x^n}{1-x}\right] \quad \text{[Eq G8]}$$

Substituting the identity from Eq G5 into Eq G8, the following is obtained:

$$M = \frac{1+i}{1+I}\left[\frac{1-\left(\frac{1+i}{1+I}\right)^n}{1-\left(\frac{1+i}{1+I}\right)}\right] \quad \text{[Eq G9]}$$

which is simplified in the following steps to obtain the final expression for the PV multiplier given in Eq G1.

$$M = \frac{(1+i)\left[1-\left(\frac{1+i}{1+I}\right)^n\right]}{(1+I)-\left[(1+I)\left(\frac{1+i}{1+I}\right)\right]} \quad \text{[Eq G10]}$$

$$M = \frac{(1+i)\left[1-\left(\frac{1+i}{1+I}\right)^n\right]}{(1+I)-(1+i)} \quad \text{[Eq G11]}$$

$$M = \frac{(1+i)\left[1-\frac{(1+i)^n}{(1+I)^n}\right]}{(I-i)} \quad \text{[Eq G12]}$$

Finally:

$$M = \frac{(1+i)\;[(1+I)^n - (1+i)^n]}{(1+I)^n\,(I-i)} \quad \text{[Eq G1]}$$

Eq G1 is solved as follows for the example problem in which $I = 0.10$, $i = 0.12$, and $n = 5$ years.

$$M = \frac{(1.12)[(1.10)^5 - (1.12)^5]}{(1.10)^5\,(1.10 - 1.12)} = 5.27943 \quad \text{[Eq G13]}$$

Multiplying the first-year cost of $90,000 by M, the 5-year PV fuel oil cost of $475,148 is obtained, which compares to the result obtained by the relatively lengthy tabular method provided in Tables G1 and G2.

Comparative Present Value Costs

The PV cost comparison is shown in Table G3. The least investment alternative is use of military waste only in a system at Ft. Bragg to produce steam for heating and cooling. The system with the largest benefits is use of all military and civilian waste in a system at Ft. Bragg to generate steam for heating and cooling.

Tables G4 and G5 show computations of the savings/investment ratio of each CRE scenario vis-a-vis the least cost alternative. The most cost-effective system is Scenario 2A, with a ratio of 3.74/1.00 and a corresponding payback period of about 2.9 years.

Table G3

Computation of 25-Year (FY81-FY05) Present Value of Annual Costs of CRE Scenarios

Item	FY77	Escalation Rate FY78	FY79	FY80	25-Year Inflation Rate (%)	25-Year PV Multiplier	Energy-Recovery Scenario 1A	1B	2A	2B	3A	3B
Plant Operating and Maintenance Costs (Debits)												
Labor	9.7	8.3	8.3	8.3	3.50	12.45	2,333.1	2,333.1	3,205.9	3,205.9	4,620.2	4,620.2
Electrical power	16.0	16.0	16.0	16.0	6.075	16.13	485.1	600.0	833.9	1,040.4	1,667.8	2,063.0
Vehicle fuel	12.0	16.0	16.0	16.0	9.00	22.25	1,270.5	1,270.5	2,287.3	2,287.3	4,369.9	4,369.9
Combustor fuel	12.0	16.0	16.0	16.0	9.00	22.25	271.5	1,844.5	356.0	3,186.2	918.9	6,325.7
Water	3.0	3.0	3.0	3.0	3.50	12.45	69.7	69.7	98.4	98.4	100.8	100.8
Maintenance and repairs	9.7	8.3	8.3	8.3	5.00	14.44	1,524.9	2,535.7	1,961.0	3,155.1	2,451.9	3,856.9
Ash and residue disposal	4.0	4.0	4.0	4.0	4.00	13.07	248.3	248.3	819.5	819.5	1,684.7	1,684.7
Total plant operating debits							6,203.1	8,901.8	9,562.0	13,791.9	15,814.2	23,021.2
Credits (Avoided or Offset Costs)												
Labor							615.0	615.0	827.9	827.9	1,274.9	1,274.9
Electrical power							372.5	2,961.5	442.0	3,511.5	645.2	6,022.9
Water		(as above)					14.9	14.9	19.9	19.9	33.6	33.6
Maintenance and repairs							226.7	226.7	327.8	327.8	505.4	505.4
Recovered ferrous metals	4.0	4.0	4.0	4.0	4.0	13.07	218.3	218.3	397.3	397.3	758.1	758.1
Fuel oil							16,393.8	16,393.8	24,846.6	24,846.6	32,914.4	32,914.4
Total plant operating credits							17,841.2	20,430.2	26,861.5	29,931.0	36,131.6	41,508.4
Plant Annual PV Economy: Debits Less Credits							-11,638.1	-11,528.4	-17,299.5	-16,139.1	-20,317.4	-18,487.2
Capital (FY81 dollars)	9.7	8.3	8.3	8.3	NA	NA	5,293.7	8,801.0	6,809.2	10,955.6	8,532.7	13,392.6
Total Plant Economy: PV Annual Costs Plus Capital							- 6,344.4	- 2,727.4	-10,490.3	- 5,183.5	-11,784.7	- 5,093.6

Negative sign is effective savings

Table G4

Summary of CRE Scenario PV Costs

Alternative	Investment Cost	20-Year Net PV O&M Cost	20-Year PV Total Cost
1A	5,293.7	−11,638.1	− 6,344.4
2A	6,809.2	−17,299.5	−10,490.3
1B	8,801.0	−11,528.4	− 2,727.4
3A	8,532.7	−20,317.4	−11,784.7
2B	10,955.6	−16,139.1	− 5,183.5
3B	13,392.6	−18,487.2	− 5,093.6

Table G5

Computation of Savings/Investment Ratios of CRE Scenarios

	All Cost Data $000				
1. Least Investment Cost Alternative: 1A					
2. Test Alternatives	**2A**	**1B**	**3A**	**2B**	**3B**
3. Net Investment Cost for Test Alternatives	6,809.2	8,801.0	8,532.7	10,995.6	13,392.6
4. Net Investment Cost for Least Investment Alternative	5,293.7	5,293.7	5,293.7	5,293.7	5,293.7
5. Differential Investment for Test Alternatives (3 - 4)	1,515.5	3,507.3	3,239.0	5,701.9	8,098.9
6. PV Annual Cost for Test Alternatives	−17,299.5	−11,528.4	−20,317.4	−16,139.1	−18,487.2
7. PV Terminal Value for Test Alternatives			Negligible		
8. Net PV Future Costs for Test Alternatives (6 - 7)	−17,299.5	−11,528.4	−20,317.4	−16,139.1	−18,487.2
9. PV Annual Cost for Least Investment Alternative	−11,638.1	−11,638.1	−11,638.1	−11,638.1	−11,638.1
10. PV Terminal Value for Least Investment Alternative			Negligible		
11. Net PV Future Cost for Least Investment Alternative (9 - 10)	−11,638.1	−11,638.1	−11,638.1	−11,638.1	−11,638.1
12. Differential Savings for Test Alternatives (11 - 8)	5,661.4	− 109.7	8.679.3	4,501.0	6,849.1
13. Savings/Investment Ratios (12/5)	3.74	Negative	2.68	0.79	0.85
14. Years to Payback	2.91	—	4.34	> 20	> 20

APPENDIX H:

DESCRIPTION OF PACKAGE CRE SYSTEMS

Introduction

This appendix provides a general technical discussion of four currently available package CRE systems. Because the systems share a similar process flow, the major thrust of the discussion is toward the uniqueness of the combustion equipment. It is emphasized that development of most package combustors has been relatively recent and that their application to energy-recovery systems is not without technical problems.

Process Flow

The process flow for all package CRE systems is fundamentally the same. Mixed solid waste is collected and delivered to a CRE facility where it is weighed and processed. The main processing operations are usually size reduction by shredding, temporary storage, burning, and use of heated offgases to produce saturated steam in a heat exchanger located after the furnace. A surge area is provided in the processing line. Appurtenances include water treatment, ash removal, and pollution control equipment.

Judicious design of a package CRE system can effect significant economic savings over the facility life. To minimize capital and annual costs, the CRE facility usually houses all operations and is located either near steam users or adjacent to a steam production plant. The CRE system should be designed with a high degree of redundancy to insure continuity in both waste disposal and energy production; sister units for moderate- and high-maintenance hardware such as shredders should be provided. Labor requirements for CRE systems designed to accommodate the typical small-scale military solid waste stream are usually comparatively small. Two full-time men can operate a facility that processes up to 6 tons/hr. For larger capacity systems, the labor crew may include a weighmaster, shredder operator, boiler operator, ash handler, front-end loader or crane operator, general laborers or helpers, and a supervisor. New manpower requirements can be reduced considerably by designing a system for maximum automation, by locating the CRE facility near an existing boiler plant and making use of its staff, and by specifying multiple tasks for workers. Implementing a CRE system often effects changes in solid waste collection vehicle routing that reduce overall annual disposal costs. By using solid waste as a fuel to produce steam, substantial quantities of increasingly expensive conventional fuels can be conserved. Recovery of large amounts of metals and glass in the solid waste can bring in additional revenue.

Solid waste deliveries are weighed at the CRE facility's entrance by a standard platform scale. The weigh station may be manned or automatic. While requiring a somewhat higher capital outlay, an automatic system usually proves less costly than a manned one over the facility life. An automatic system may include either a standard automatic printing device or a remote-reading electronic system. In the latter case, weights may be recorded in the operations office inside the CRE facility. A signal at the weigh station indicates when the truck weight has been recorded.

There are various means of initially handling solid wastes delivered to the CRE facility. For larger waste streams, a pit-and-crane operation may be desirable. Waste is dumped directly into the pit, which is usually designed to accommodate surge quantities. A ceiling-mounted crane moves material from the pit to further processing. Oversized bulky wastes are removed, and incombustible bulkies are separated for disposal or recycling. Combustible materials either too large or of too great a structural strength to be handled with mixed solid waste in subsequent processing stages may be diverted to an auxiliary heavy-duty shredder for breakdown. A system using a tipping floor and front-end loader is an alternative to the pit-and-crane operation. Delivered solid waste is dumped on the floor and moved by the loader either to a temporary storage area or directly to processing. Bulkies are handled as described above. Some municipal scale systems employ floor hoppers. Delivered solid waste is dumped through the hopper grate and conveyed to further processing. Such systems have been moderately problematic from the standpoint of controlling oversized bulky materials.

From the delivery point, solid waste may be conveyed to temporary storage, to further processing, or directly to the incinerator. Although most currently marketed package incinerators are designed to accommodate unprocessed solid waste, it is sometimes preferable to shred the material in CRE applications. Shredding loosens and reduces the waste to a smaller and more easily handleable particle size range, increases the surface/volume ratio and hence

the material's combustibility, and by mixing, makes the charge more homogeneous than unprocessed solid waste. Shredding increases the ease and efficiency of thermal processing and gives stability to heat exchanger performance. A wide variety of size reduction hardware is currently available, and selection of an appropriate unit depends heavily on the nature and quantity of the solid waste. In general, heavy-duty, vertical-feed, reversible-drive hammermills with replacable hammer tips are adequate for the typical military base solid waste stream. Complete redundancy at this processing stage is desirable, since shredders are high-maintenance items, and continuous, reliable processing of solid waste is necessary.

As a rule, it is preferable to keep solid waste moving through a CRE system. This strategy avoids many difficult handling problems associated with storage of moist, putrescible materials. Often, however, temporary (up to 3 days) storage is necessary, which can be accomplished in the receiving pit. Shredded solid waste can also be stored in agitated bins, but this approach usually means higher capital investment and operating costs. If a tipping floor is used, it should be adequately sized to accommodate storage and surge requirements.

Shredded solid waste is fed into the package incinerator as required to operate the CRE system at nominal capacity. Incinerator feeding is either continuous, semicontinuous, or batch, depending on the unit's design. Batch-fed incinerators are usually unfavorable in CRE applications, because they make it difficult to maintain continuity in steam production and solid waste disposal.

The final stage of the incineration process is usually afterburning. In CRE applications, afterburners should be temperature-activated and should limit the temperature range of combustion products entering the heat exchanger.

Three types of heat exchangers can be used. Steam is generated in watertube or firetube package boilers or, as in the case of the recently developed augered-bed system, in a coiled heat exchanger between the furnace and air pollution control hardware. Firetube boilers have been used in series with both rotary-kiln and starved-air incinerators with only minor difficulty. The firetube boiler should be selected for once-through design, since entrained fly ash will be deposited if there are multiple turns in the gas pass.

The load-carrying and response characteristics of watertube boilers are superior to those of firetube units. It is desirable to precede a water-tube boiler with a waterwall quench section where the bulk gas temperature is reduced to below 1900°F. Above this temperature, entrained particles impinging on tubes tend to adhere, making cleaning difficult, promoting fireside metal wastage, and upsetting the system's design heat balance.

Whichever type of boiler is selected, it is necessary to install hoppers beneath the tube passes and to furnish sootblowers. The design should also provide for automatic ash handling. To maintain consistent steam output when incinerators are down, there should be burners and kindred appurtenances for direct firing of the heat exchanger with clean fuel. When heat exchangers are clean-fuel-fired, gases may be passed through bypass breeching around the air pollution control equipment.

Most available package incinerators include at least semicontinuous ash and residue removal. This phase is discussed separately in appropriate incinerator sections.

Proven, available air pollution control equipment is the next step in the package CRE system. Since mixed solid waste can contain up to 25 percent ash, high mass emission rates may be expected. Wet or dry pollution abatement systems can be used; however, wet systems consume large amounts of power and cause a water treatment problem. Venturi scrubbers and high draft water spray cyclones have successfully reduced emissions from CRE systems, but their use might mean higher capital and annual costs from water treatment requirements. If a wet ash removal system is used, it is often convenient to use scrubber wastewater for quenching. Use of a scrubber usually requires a demister to inhibit mechanical deposition of droplets on the ID fan. Baghouses and electrostatic precipitators are the chief alternative dry collection systems. To reduce the possibility of filter fabric damage, a cyclone separator is used before the baghouse. High-temperature corrosion and abrasion-resistant media such as fluorocarbon are recommended. Utility operating costs of both systems are generally comparable. A baghouse normally has a large ID fan horsepower requirement, since pressure drops across the unit can be great. Precipitators are large electricity consumers. A precipitator-based design places a low-efficiency cyclone ahead of the ash storage bin to remove any hot cinders which may cause an explosion.

Material collected in the cyclone for both the fabric filter and electrostatic precipitator systems should be quenched before being admitted to the ash bin. A precipitator system may require preconditioning of the flue gas with sulfur trioxide. Since solid waste contains very little sulfur, the particulate material's resistivity at the collection electrode may adversely affect the unit's collection efficiency.

Preparing and using solid waste as a fuel can create numerous environmental hazards. Air hoods are required for shredders whose off gases contain up to 0.05 percent of the feed as entrained dust. High chloride emissions from the combustion process are possible, because the heavier fractions of solid waste may contain substantial quantities of polyvinylchlorides. If large quantities of plated metals are present, high concentrations of zinc, tin, cadmium, lead, and antimony will be emitted as a submicron heavy aerosol formed by reducing and evaporating these metals in the fuel bed and oxidizing the vapor as it passes through the flame front. The metals will either coalesce as a heavy metal aerosol or plate out on the ash matrix. Because of varying resistivities, some trace metals may pass through an electrostatic precipitator. By taking combustion air from solid waste delivery and storage areas, odors can be controlled effectively. Noise from shredding operations can be reduced either by properly designing the unit housing or by installing acoustic partitions. For safety, shredders should be surrounded by blast partitions, with low-resistance blast panels installed on the ceiling.

Depending on the nature and quantity of solid waste being processed, profitable materials recovery stages may be included in the CRE system. A variety of proven hardware is available for magnetics recovery, and can be placed either before or after the shredding stage. If economical, an aluminum recovery system can follow magnetics recovery. Separation of glass and cullet is more difficult, usually requiring additional shredding and agitated screening and wet recovery stages such as flotation. Such recovery systems require high investment and operating costs. It has been demonstrated frequently that the most economical way to isolate salvageable materials from other wastes is to conscientiously practice source segregation.

Rotary-kiln Incinerator

The primary combustion chamber of a rotary-kiln incinerator is a slightly inclined, refractory-lined cylinder (Figures H1 and H2). In most commercially available units, the shell is prefabricated, so that the kiln may be shipped as a unit. Refractory materials are customarily made to specifications given in terms of thermal tolerance and resistance to abrasion and corrosion.

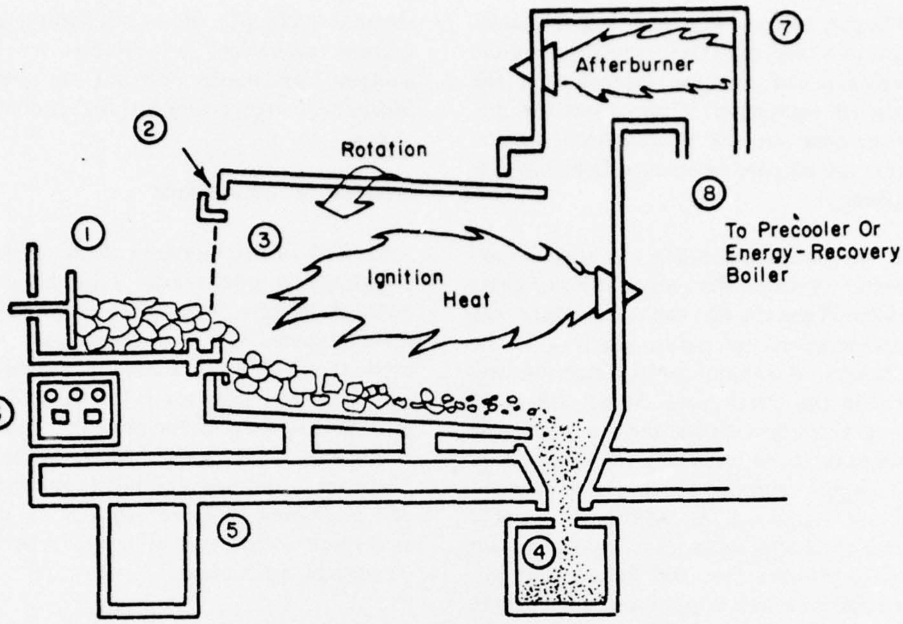
During combustion, the kiln rotates around its longitudinal axis of symmetry, continually mixing the charge mechanically as it is being conveyed to the discharge end. The constant motion effectively breaks cake layers on the charge's surface, continually exposing fresh surfaces and increasing combustion efficiency. In a well-operated unit, there is approximately 92 percent combustion. The combustible material dries quickly, ignites, and burns thoroughly. Combustion air is preheated by reflected heat from within the kiln. The ignition burner is located at the discharge end of the kiln and may be fueled with light or heavy oil, gas, or flammable liquid waste material. Temperatures sufficient to sustain ignition are normally maintained by the burning charge after startup. Additional fuel can be supplied to the kiln when wastes having a heating value too low to support self-combustion are being burned. This auxiliary fuel may be mixed with the charge or burned in either an auxiliary burner or the ignition burner.

In CRE systems using the rotary-kiln unit, the package boiler is installed after the afterburner. The energy-recovery efficiency of these systems can range between 60 and 75 percent, including boiler and breeching losses.

The rotary kiln can burn mixed solid waste as received. Oversized bulky wastes are usually shredded to insure complete combustion within reasonable detention times. Feeders on commercially available units are designed to accommodate feed variability. Sludges and similar wastes are usually mixed with a variable supply of solid waste before charging.

A ram feeder can be used to charge the primary chamber. Ash is continuously discharged through a port in the bottom of the refractory-lined firing hood at the end of the unit. The discharge end firing hood is equipped with labyrinth seals and heat-resistant gaskets to inhibit air leakage.

The detention time of solid material passing through the kiln is controlled by the cylinder's slope (usually 20 degrees) and its rotational speed. The velocity of gases passing through the cylinder is



1 Coarse RDF Auto-Feed (Hopper, *Pneumatic Feed, Slide Gates*)
2 Forced Air
3 Refractory-Lined Rotating Cylinder (Primary Chamber)
4 Ash Hopper (Incombustibles)
5 Support Frame And Piers
6 Control
7 Secondary Chamber
8 To Appurtenances

Figure H1. Rotary-kiln incinerator.

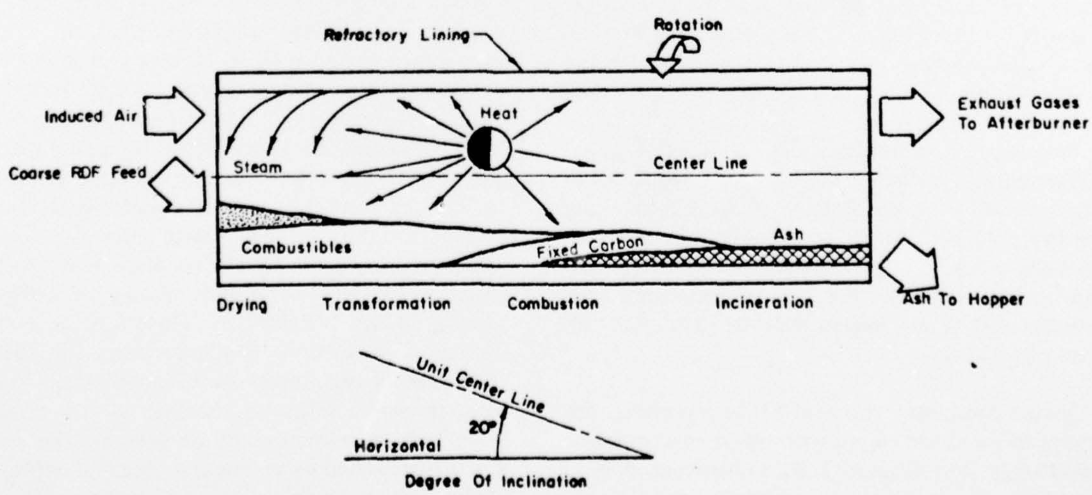


Figure H2. Operation of rotary-kiln incinerator.

determined largely by combustion air requirements. Gas velocity is partially controlled by modulating the induced draft fan and damper, located after the pollution control equipment. Gases from the primary chamber pass into the afterburner's section, where residual volatiles are combusted in an oxygen-rich atmosphere.

Automatic temperature controls are used. A primary pyrometer monitors the temperature of gases leaving the kiln. When the exit gas temperature falls below a predetermined set point, gas flow to the burners increases. A second control monitors gas temperatures in the afterburner. When the afterburner temperature falls below the set point, the burner heat release increases. When the temperature exceeds the upper set point, the burner automatically modulates downward. An additional optional temperature control apparatus from a gas precooler shuts down the burners, fan, and feeder when gas temperatures exceed a safe upper limit. An alarm in the control module activates after safety shutdown.

Rotary-kiln incinerators normally operate with 140 percent theoretical air in the primary chamber. Operating temperatures in the kiln are usually between 1400°F and 2300°F, with a recommended operating range between 1200°F and 2400°F.

Due to thermal losses and the addition of excess air, gases leaving the afterburner section normally range between 1500°F and 1880°F. If these gases must pass directly to the air pollution control equipment, they must be precooled by either a water spray, addition of tempering air, or a heat exchanger. In the latter case, recovered heat may be used to heat combustion air or used elsewhere in the processing plant.

Bottom ash and residue drop into a water-sealed ash-handling unit below the kiln. A grate is sometimes placed in front of the bottom ash-handling hardware to trap oversized combustibles such as cans and pipes, but this can cause exit blockage and ash backup. If the bottom ash is sufficiently fine, water-cooled screw augers can be used for ash removal.

Some available rotary-kiln incinerators are equipped for either countercurrent or concurrent or gas/charge flow (Figure H3). Concurrent flow is used for drier, more heterogeneous wastes. During carbonization of solid fuels, flue gases are completely burned in the afterburner, permitting higher thermal loading in the combustion zone. Countercurrent operation is suitable for incinerating sludges. Combustion products are used to dry the incoming charge, permitting higher combustion efficiency.

Starved-air Incinerator

Starved-air incinerators have recently gained popularity in solid waste incineration, principally because inexpensive, small-capacity units are being manufactured. Larger package units (1.25 ton/hr capacity range) are available in two different major configurations (Figures H4, H5, and H6). These units both operate on the same principle: the charge is fed into a primary chamber, ignited, and then burned in a secondary chamber to which excess air and additional heat are supplied. A well-operated starved-air incinerator will achieve between 80 and 93 percent combustion.

A drawback to the starved-air system is the lack of charge mixing. This deficiency normally prevents the material from being completely burned and often causes furnace pulsations. As a result, energy-recovery efficiencies average only 55 percent, but can be as high as 75 percent. Temperature is controlled by adding air and auxiliary fuel to the afterburner and sometimes modulating the air supply. However, in an improperly operated unit, the carbon content of ash emitted from the furnace is often high.

Several vendors have starved-air units with semi-automatic feeders and semi-continuous ash-removal systems. Currently, however, fully automatic ash removal is not proven technology. Because of high temperature slagging in the primary chamber, the unit has a comparatively large fraction of downtime, with corresponding high operating and maintenance costs. Most available units require moderate quantities of auxiliary fuel, although recently developed combustion controls which automatically modulate excess air in the afterburner have reduced clean fuel requirements. Underfire air has been modulated in attempts to achieve constant quality of off-gases passing to the afterburner. There are two basic starved-air incinerator configurations. The first is comprised of two "piggy-back" combustion chambers, in which refuse is charged to the primary (lower) chamber through an air curtain. The entryway is surrounded by an annular ring of compressed air jets, which provide a conical air blast that prevents flareback when the charging door is opened. When the temperature in the primary chamber

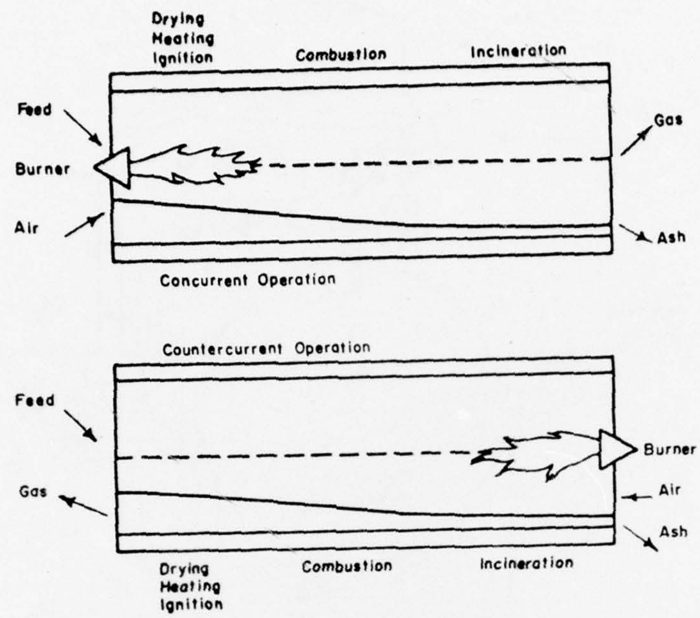


Figure H3. Concurrent and countercurrent operation of rotary-kiln incinerator.

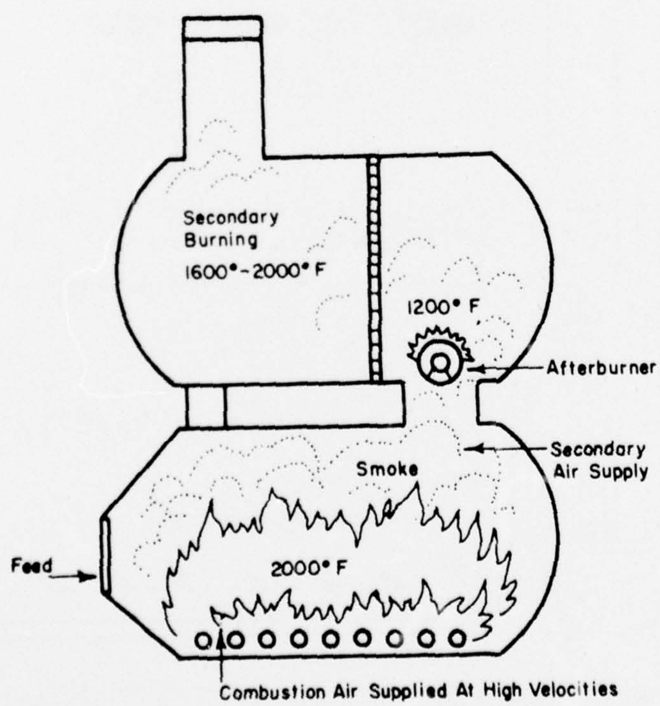


Figure H4. Starved-air incinerator (first major configuration).

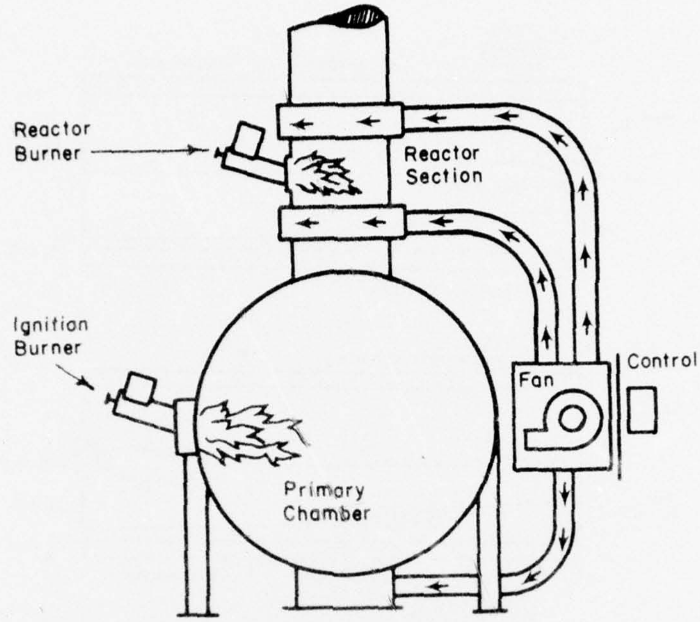


Figure H5. Front view of starved-air incinerator (second major configuration).

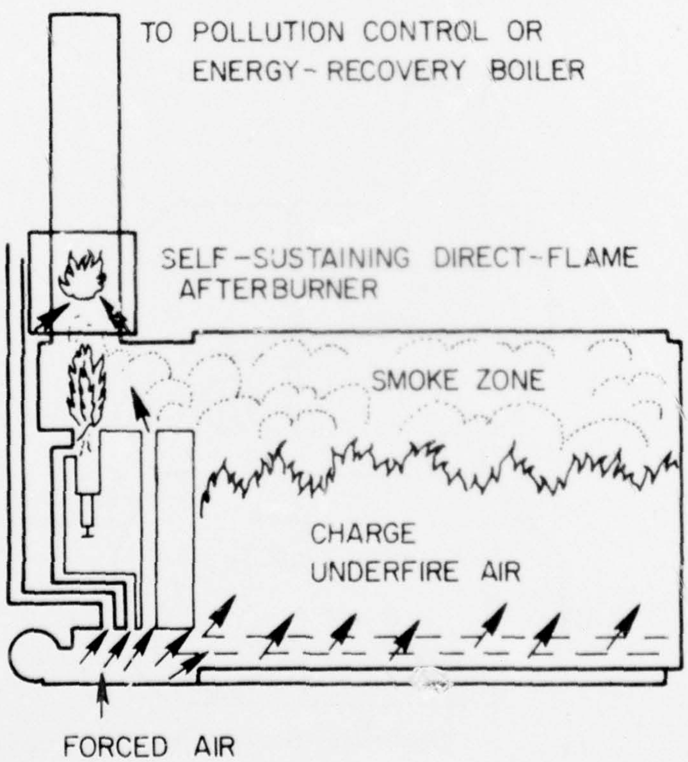


Figure H6. Side view of starved-air incinerator (second major configuration).

reaches approximately 600°F, a stream of air passes over the fire. Incombustible materials precipitate to the grateless bottom of the chamber, and the remaining solids, gases, and odors rise to the upper or secondary chamber where excess air is added. Thorough mixing is maintained by baffling excess air as it is added. Temperatures in the primary chamber range to 1500°F, and usually to 1200°F in the secondary chamber.

Most units of this configuration feature an automatic temperature-activated indicator which signals the operator when charging should begin and end. On small units, the charge is delivered manually to the primary chamber. Batch ram loaders are normally provided with larger units. Commercially available package starved-air incinerators, which are proven in CRE applications, range in capacity from 200 to 2400 lb/hr for Incinerator Institute of America (IIA) Type 1 waste.

The second type of starved-air incinerator (Figures H5 and H6) uses a substantially smaller secondary combustion chamber. Intermediate units can handle from 1350 to 8100 lb/loading, and larger units can be built to specification. The largest proven incinerator of this configuration can accept a charge of more than 36,000 lb.

These units process the charge similarly to the units discussed previously. The charge is partially pyrolyzed in the primary chamber, and the products are then passed through an afterburner located above the primary chamber. The afterburner is clean fuel-fired, and effects complete combustion of the pyrolysis products in an excess air environment. Newer models feature an afterburner fired by a mixture of pyrolysis products from the primary chamber and preheated air, which reduces clean fuel requirements.

The chief drawback to this type of starved-air system is that when the charge has been completely processed, the furnace must be shut down and allowed to cool before another batch can be loaded safely. Recent design innovations employing semi-continuous charging and ash removal have not been proven.

Basket-grate Incinerator

Like the rotary-kiln and starved-air units, the basket-grate incinerator (Figure H7) is capable of firing mixed solid waste as delivered. Available units have input capacities ranging between 160 and 6000 lb/hr of IIA Type 1 waste. The primary chamber is an inclined (30 degrees) truncated cone-shaped grate supported by an externally driven frame. The chamber is insulated, and the shell is normally fabricated of structural steel plate.

The basket grate is semi-continuously charged with material to approximately 20 percent of its total volume and rotated slowly around the cone centerline. The inclination and rotation cause heavier materials to fall toward the larger (outer) basket diameter and the smaller materials to fall toward the smaller (inner) diameter. The three-dimensional self-raking effect of the virtually endless grate maximizes mechanical and thermal destruction of the charge.

The charge is retained on the grate until it is reduced to a size which can pass through the grate slots (about 0.125 in.) into an ash hopper or secondary incineration chamber. Large incombustibles can be removed periodically from the grate by means of a grated plate which can be lowered from the basket bottom. Some problems have been experienced with bulky incombustibles accumulating in the cone which reduce available combustion volume, and with fine combustibles sifting through the grate and burning in the ash hopper. Negative relative pressure within the primary chamber induces air through the ash collector, so that ash and residue leakage is not a problem. An external fan mounted on the swivel frame supplies primary air to the furnace. Distribution pipes divert a portion of the air directly beneath the firebed to provide underfire air. Part of the combustion air is tangentially injected into the secondary combustion chamber located above the firebed. This causes a turbulence zone which effects efficient mixing and combustion. Afterburning is normally self-sustaining. Gases leave the secondary combustion chamber through the crown.

Temperatures in the secondary chamber range between 1500°F and 2100°F. In CRE applications, the afterburner is fired to maintain high temperatures in the gases before they leave the exit port and pass to the heat exchanger. Temperature is controlled by automatically varying the quantities of air entering the primary and secondary chambers in an inversely proportional manner. In normal operation, high off-gas temperatures can be maintained at approximately 70 percent excess air. Auxiliary fuel is usually

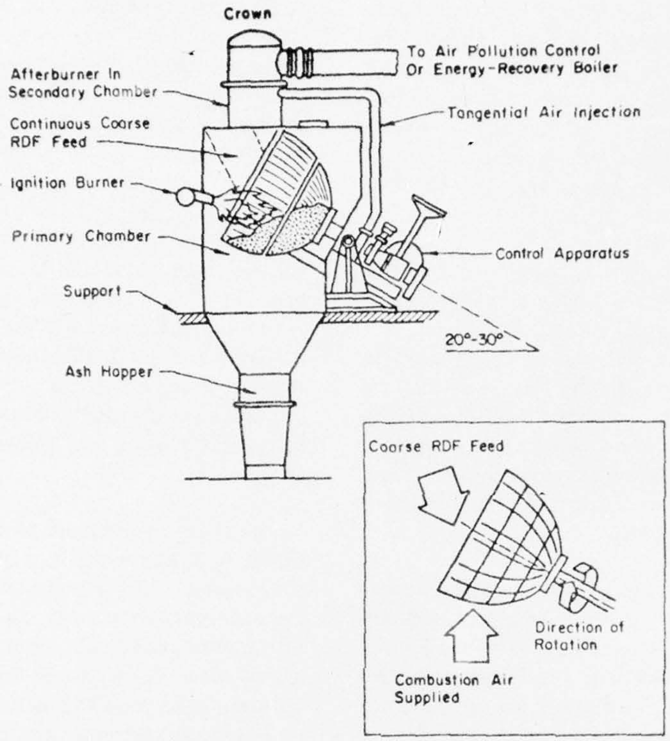


Figure H7. Basket-grate incinerator.

required only during startup, which can be completed in 15 min. After the unit has been brought on-line and stabilized, no additional fuel is necessary.

Available units achieve 90 to 96 percent reduction of combustible materials for IIA Type 1 waste. The quantity of incombustible residue remaining in the ash rarely exceeds 5 percent. Because the unit is designed to maximize combustion, energy-recovery efficiencies average 68 percent.

Augered-bed Incinerator

Although the augered-bed incinerator is a very recent development and therefore unproven, successful demonstrations indicate that engineering problems are relatively minor. Units are expected to go on-line within a year, and experience soon thereafter will provide the operating data necessary for improved design. Currently, manufactured package units have capacities of 1 and 5 tons/hr.

The augered-bed incinerator is comprised of a refractory-lined cylindrical primary combustion chamber that contains a rotatable auger (Figure H8). The chamber is fed continuously by a live-bottom feed conveyor. Combustion takes place in an excess air environment as the auger conveys the charge throughout the length of the chamber. High-temperature combustion products pass through a coiled heat exchanger where steam is produced. Gases are then cleaned in a wet cyclone before passing out from the stack. Ash removal is automatic and continuous.

The unit is capable of processing mixed solid waste as delivered. Oversized bulky materials too large to pass through the feed port are separated from the delivered waste. Waste streams containing a high percentage of bulky materials can be accommodated by adding a shredder between the delivery point and the feed hopper.

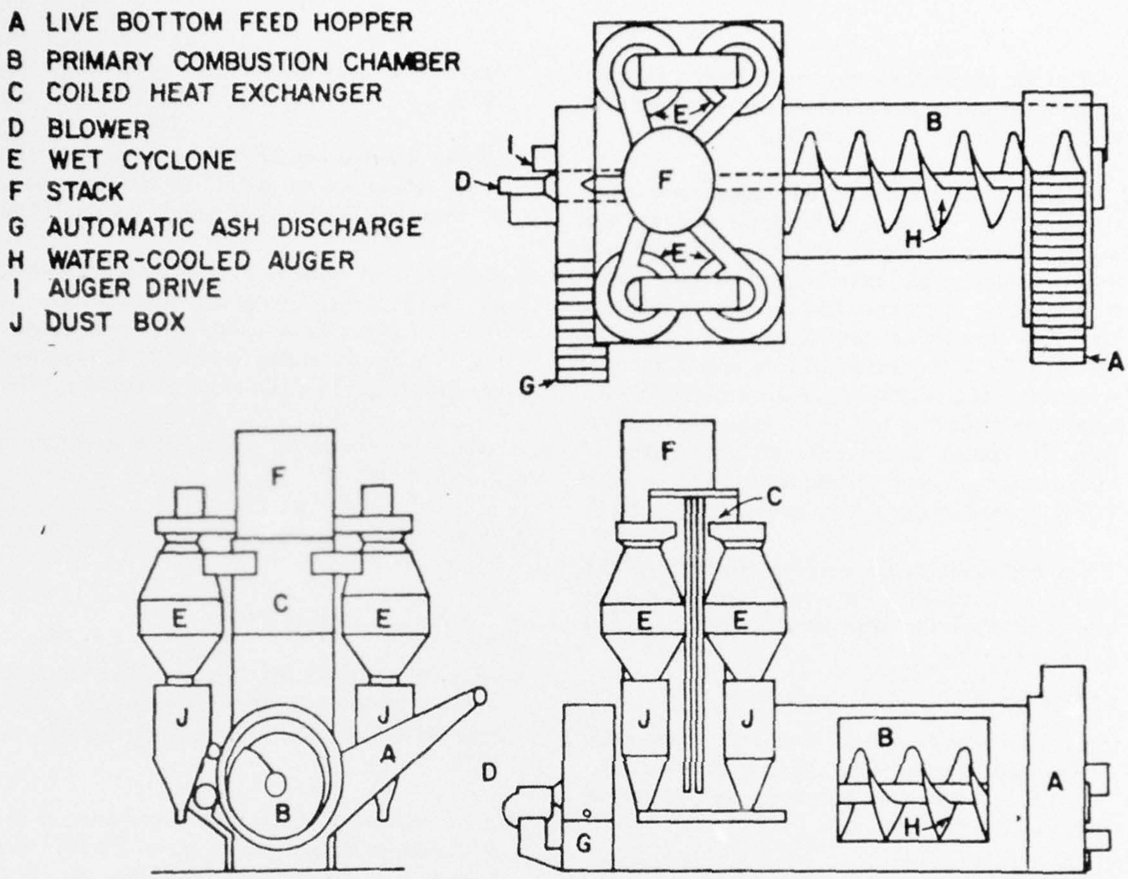


Figure H8. Augered-bed incinerator.

Processing is continuous. Solid waste enters a floor-level hopper and is moved on an inclined conveyor to the charging end of the primary chamber. The charge burns as the slowly rotating auger moves it through the primary chamber. The auger conveys ash and residue out the discharge end of the chamber to a chain belt conveyor, which transfers the mostly sterile, inert end product to temporary storage before its ultimate disposal.

The auger is a hollow spiral flight carried by a tubular shaft. Combustion air is introduced into the downstream end of the primary chamber and forced through an air passage extending along the length of the spiral flight. Forced air passes from the flight interior into the primary chamber and is discharged within the charge being conveyed by the auger. A water passage in the spiral flight cools the auger. The air then enters the upper portion of the primary chamber where off gases are burned in a second combustion zone. A well-operated unit achieves approximately 95 percent volume reduction.

An ignition burner is located at the charging end of the primary chamber. Gas or fuel is normally used, but flammable liquid wastes can also be fired. In normal operation, the ignition burner operates only during startup, which requires about 15 min. When combustion becomes self-sustained, no auxiliary fuel is required. The unit can be shut down in 20 min.

High-temperature combustion products pass through a coiled heat exchanger between the primary combustion chamber and the air pollution control equipment. Saturated steam is produced from water preheated in the spiral flight.

Available units include induced-air, counterflow wet cyclones for air pollution control as part of the package system.

Variable drive controls are provided on all functions to adapt to fluctuations in the type and quantity of solid waste being processed. Hydraulic drive

systems are provided for the auger, feeder, and ash removal apparatus, and standard belt drives are provided for blowers.

Operating experience with the augered-bed incineration will provide data for improved design. Data are required concerning (1) possible fouling and tube metal wastage in the heat exchanger section caused by exposure to combustion process emissions; (2) steam production performance; (3) results of exposing the auger material to continued thermal stress; (4) extent of treatment required both for heat exchanger feedwater and for sludge from the air pollution control equipment; (5) the degree of maintenance required; and (6) the quantity of clean fuel consumed by the unit in normal operation.

The computed energy-recovery efficiency of this system is 65 percent; operating experience is required to determine whether this is an accurate design parameter.

REFERENCES

Combustion Fundamentals for Waste Incineration (American Society of Mechanical Engineers Research Committee on Industrial and Municipal Wastes, 1975).

Conversion of Central Heating Plant Boilers to Refuse Derived Fuel Firing (Department of the Army, New York District, Corps of Engineers, 1975).

Economic Analysis and Program Evaluation for Resource Management, AR 11-28 (Department of the Army [HQDA DACA-CAF], December 1975).

Hathaway, S. A. and J. P. Woodyard, *Technical Evaluation Study: Energy-Recovery Utilization of Waste at Puget Sound Naval Shipyard, Bremerton, WA*, Technical Report E-89 (U.S. Army Construction Engineering Research Laboratory, 1976).

Incineration Standards (Incinerator Institute of America, 1970).

National Atlas of the United States (U.S. Geological Survey, 1970).

NCRR Bulletin (Spring 1973).

Niessen, W. R. and S. H. Chansky, "The Nature of Refuse," *Proceedings of 1970 Incinerator Conference* (American Society of Mechanical Engineers, 1970).

Phase I Feasibility Study: Refuse Incinerator/Heat Reclamation Boiler Facility, Naval Station, Mayport, Florida (Greenleaf/Telesca, Inc., December 1975).

SI CONVERSION FACTORS

Non-Metric Unit	Dimension	Multiplied By	Yields Metric Unit
British thermal unit	ML^2T^{-2}	1.055×10^{-3}	Joule
Cubic foot	L^3	2.832×10^{-2}	Cubic meter
Cubic yard	L^3	0.7646	Cubic meter
Fahrenheit degrees	θ	5/9 (°F-32)	Celsius degrees
Foot	L	0.3048	Meter
Gallon	L^3	3.785×10^{-3}	Cubic meter
Gallon	L^3	3.785	Liter
Inch	L	2.540	Centimeter
Pound	MLT^{-2}	0.454	Kilogram
Short ton	MLT^{-2}	907.1848	Kilogram
Short ton	MLT^{-2}	0.9078	Metric ton
Square foot	L^2	9.3×10^{-2}	Square meter
Square yard	L^2	0.8361	Square meter
Yard	L	0.9144	Meter

CERL DISTRIBUTION

Chief of Engineers
ATTN: DAEN-MCZ-S
ATTN: DAEN-ASI-L (2)
ATTN: DAEN-FEE-A
ATTN: DAEN-FE
ATTN: DAEN-RD
ATTN: DAEN-CWZ-R (3)
ATTN: DAEN-CWR-R (2)
Dept of the Army
WASH DC 20314

U.S. Military Academy
ATTN: Dept of Mechanics
ATTN: Library
West Point, NY 10996

The Engineering School
Technical Information Br.
Archives Section (Bldg 270)
Ft Belvoir, VA 22060

USA Engineering School
ATTN: ATSEN-DT-LD (2)
Ft Belvoir, VA 22060

Commander, TRADOC
Office of the Engineer
ATTN: ATEN
Ft Monroe, VA 23651

Director
USA Cold Regions Research
Engineering Laboratory
PO Box 282
Hanover, NH 03755

Deputy Chief of Staff
for Logistics
US Army, The Pentagon
WASH DC 20310

The Army Library (ANRAL-R)
ATTN: Army Studies Section
Room 1A534, The Pentagon
WASH DC 20310

Commander in Chief
US Army, Europe
ATTN: AEAEN
APO New York, NY 09403

Each Division Engineer
US Army Engineer Division
ATTN: Library
ATTN: Chief, Engr Div

Each District Engineer
US Army Engineer District
ATTN: Library
ATTN: Chief, Engr Div

Commanding General
USA Engr Command, Europe
APO New York, NY 09403

Engineer
US Army, Alaska
APO Seattle, WA 98749

Commanding General, 5th USA
ATTN: Engineer
Ft Sam Houston, TX 78234

Commanding General, 6th USA
ATTN: Engineer
Presidio of San Francisco, CA 94129

Defense Logistics Studies
Information Exchange (2)
US Army Logistics Management Center
ATTN: DRXMC-D
Ft Lee, VA 23801

Department of the Army
Headquarters US Army Electronics
Command
ATTN: AMSEL-PL-ST/Mr. Grant (25)
Ft Monmouth, NJ 07703

Each Facility Engineer as listed
in DA PAM 210-1

Commander, Naval Facilities
Engineering Command
ATTN: Code 04
200 Stovall St
Alexandria, VA 22332

Chief, Naval Operations
ATTN: The Library
Dept of the Navy
WASH DC 20360

Naval Civil Engineering Lab
Technical Library Code L31
Port Hueneme, CA 93043

AFWL/Civil Engr Division
Kirtland AFB, NM 87117

AF/PREE
Bolling AFB, DC 20332

AF/RDXT
WASH DC 20330

AF Civil Engr Center/XRL
Tyndall AFB, FL 32401

HQDA (SGRD/Chief),
Sanitary Engr Br
WASH DC 20314

Defense Documentation Center
ATTN: TCA (12)
Cameron Station
Alexandria, VA 22314

Office of Management Svc,
MS 110-FAA
800 Independence Ave, SW
WASH DC 20553

Library of Congress (2)
Exchange and Gift Div
ATTN: Federal Documents Section
WASH DC 20540

Bldg Research Advisory Board
National Academy of Sciences
2101 Constitution Ave
WASH DC 20418